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~~ROCKY MOUNTAIN ARSENAL, NORTH BOUNDARY CONTAINMENT/TREATMENT SYSTEM, OPERATIONAL~~
ASSESSMENT REPORT, FY85/FY86

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13. ABSTRACT (Maximum 200 words)

THIS REPORT IS THE SECOND IN A SERIES OF REPORTS PREPARED TO DOCUMENT AND ASSESS THE STATUS AND OVERALL OPERATIONAL PERFORMANCE OF THE NORTH BOUNDARY CONTAINMENT/TREATMENT SYSTEM. THE REPORT CONSISTS OF THREE VOLUMES: VOLUME I IS THE MAIN TEXT; VOLUME II CONTAINS THE HYDROGEOLOGIC AND CONTAMINANT DISTRIBUTION PLATES; AND VOLUME III CONTAINS THE DATABASES DEVELOPED TO SUPPORT THE EVALUATIONS AND ASSESSMENTS MADE DURING THE STUDY.

THE OBJECTIVES OF THE REPORT INCLUDE:

1. ASSESS THE CONTINUING EFFECTIVENESS OF THE NORTH BOUNDARY SYSTEM IN PREVENTING OFF-POST MIGRATION OF CONTAMINATED GROUND WATER
2. DOCUMENT SYSTEM OPERATING PARAMETERS
3. IDENTIFY AND DOCUMENT SYSTEM IMPROVEMENTS
4. IDENTIFY AND DOCUMENT OPERATIONAL IMPROVEMENTS THAT WILL ENHANCE LONG-TERM EFFECTIVENESS.

DATA IN VOLUME II INCLUDE WEEKLY ADSORBER FLOWS, WATER QUALITY, AND WATER

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ROCKY MOUNTAIN ARSENAL
NORTH BOUNDARY CONTAINMENT/TREATMENT SYSTEM
OPERATIONAL ASSESSMENT REPORT

FY85/FY86

VOLUME I
REPORT

by

Program Manager Staff Office
Program Manager, Rocky Mountain Arsenal
Contamination Cleanup
Aberdeen Proving Ground, Maryland 21010-5401

June 1987

EXECUTIVE SUMMARY

Introduction

This report is the second in a series of reports prepared to document and assess the status and overall operational performance of the North Boundary Containment/Treatment System. The report consists of three volumes: Volume I is the main text; Volume II contains all of the hydrogeologic and contaminant distribution plates; and Volume III contains the data bases developed to support the evaluations and assessments made during the study. The report covers the operating period from October 1984 to September 1986 (fiscal years (FY) 1985 through 1986).

Monitoring Activities

Ground Water

The ground water monitoring programs conducted during FY 85-86 consisted of the collection of water elevation data and water samples for chemical analysis to define water quality. The data were generated as part of a variety of in-house and contracted efforts. Presently, the basic ground water monitoring program for the Program Manager, Rocky Mountain Arsenal Cleanup (PM, RMA) is a regional program that consists of both on and off-post contamination assessments. The chemical analysis and water level data are maintained on the PM, RMA computer system and the Rocky Mountain Arsenal Information Center (RIC) computer. These data bases are the official record and were used as the primary source of information for the ground water assessments.

Plant Operations

Monitoring of the treatment plant included collection of data on influent and effluent flow quantities, and on quality of water at various points in the treatment system. The program is managed by personnel of the Program Manager Staff Office (PMSO) at RMA. Flow data are collected on a daily basis and a log of plant operations is also maintained daily. Process control is facilitated by weekly chemical analysis of water samples taken from strategic sampling locations within the interior of the treatment plant. Chemical analyses are performed by the analytical laboratory at RMA and the data are maintained in the PM, RMA data base by the RIC.

Summary of Operational Effectiveness

The North Boundary system was designed to capture and remove ground water organic contaminants (DIMP, DBCP, DCPD, aldrin, dieldrin, endrin and organosulfurs) to below maximum operating levels (see Table 5, page 57), so that ground water down gradient of the system would not contain concentrations of contaminants in excess of acceptable levels (standards and criteria where available). It is emphasized that the system was designed to contain and treat all of the ground water flowing in the alluvium off the North Boundary of RMA. In order to evaluate the system's ability to intercept and control ground water flow, and to treat the contaminants in this flow to an acceptable level, a system operational assessment is needed.

Ground Water Flow and Elevations

During the FY 85-86 time frame, ground water flow continued to follow historical patterns described in a previous report (Thompson et al., 1985). The flow is generally within the buried stream valley through Sections 23 and 24. The ground water flow approaching the North Boundary System is currently estimated at 200-250 gpm. For FY 85-86, the average water table level up gradient of the barrier appears to be decreasing slowly with time with the 4th Quarter FY 86 level the lowest in three years. This trend implies that the dewatering rates for FY 85-86 are approximating ground water flow rates toward the system.

The North Boundary System has continued to serve as a barrier to the alluvial ground water flow along the north boundary of RMA as evidenced in the ground water elevation maps prepared for this report (Plates 1-8 Volume II). Although the hydrologic monitoring data collected during this study still indicate that the flow in the Denver Formation is generally northward, the hydraulic driving force produced by the water levels in the alluvium upgradient of the barrier has been reduced during the FY 85-86 time frame. This reduction has resulted from a gradual decrease in ground water levels due to increased system dewatering rates.

The North Boundary System recharge continues to be less than optimal in achieving the desired distribution of ground water north of the barrier. This condition is reflected in the variability of the ground water elevations immediately north of the system. Related studies (Lutton, 1986 and PM, RMA, Task 36) are in progress that will provide specific recommendations for interim and long-term solutions to this recharge problem.

Contamination Control Operations

The North Boundary System is effectively reducing the off-post migration of contaminated ground water in the alluvial aquifer and is consistent with the system original design objectives. Although an extensive assessment of the distribution of contaminant concentrations north of the barrier is not possible due to limited data during FY85/86 in this area, the historical data, including that generated during the current study period indicate a general downward trend in contaminant concentrations over the past 7 to 8 years that the North Boundary Containment/Treatment System has operated.

Monitoring data obtained for the influent and effluent of the treatment plant indicate that the system is effectively removing organic contaminants to concentrations generally below detectable levels. No concentrations of organic contaminants (DIMP, DCPD, and DBCP) above their respective maximum operating levels were found in the effluent from the plant. Inorganic contaminants such as chloride and fluoride are not being removed by the treatment system. However, treatment plant influents/effluents are monitored for fluoride and chloride and by proper control of influent streams, the effluent fluoride concentrations is maintained below the maximum operating level at all times, and the effluent chloride concentration is on an average basis below the maximum operating level.

System Reliability

System operating reliability is an important factor in the overall effectiveness of the system. System failures can cause large fluctuations in ground water levels and hydraulic gradients. The facility alterations and repairs made during the FY 85-86 time frame markedly improved the operating reliability of the system. Modifications were made to reduce the amount of down time previously experienced due to mechanical failures. Many of these modifications were made in response to those previously recommendations by Thompson et al. (1985) during the FY 84 operational assessment of the system. The majority of the alterations and repairs during FY 86 were aimed at eliminating the problem of carbon fines migration from the adsorbers into the recharge wells. A cleanup and flushing program was conducted, the dewatering wells were cleaned and surged, and the plant filter cartridges were seated firmly with stiffeners to inhibit the migration of carbon fines which causes plugging of the recharge wells. All of these improvements will tend to improve system hydraulic conditions to enhance overall system reliability and operation.

Conclusions and Comments

Current assessment of ground water flow approaching the North Boundary System is estimated at between 200-250 gpm. The trend in water table elevations over the period FY 84-86 implies that the dewatering rates are approximating the ground water flow rates toward the north boundary. As a result of the current assessment of the North Boundary System, there remains a need to improve water recharge to facilitate a more even distribution of ground water immediately north of the system.

The North Boundary System is reducing the off-post migration of contaminated ground water as designed. The treated water being recharged north of the barrier contains levels of DIMP, DCPD, DBCP, dieldrin, endrin, aldrin, and combined organo-sulfurs generally below detectable levels. No concentrations of organic contaminants in the plant effluent were found to be above their respective maximum operating levels. The concentrations of contaminants still found in the ground water north of RMA are believed to be residuals from historical migrating contaminant plumes. Ground water in this area moves relatively slow, thus, considerable time is required for the contaminant concentrations to dissipate. The concentrations should continue to trend downward. The current assessment still indicates the need to improve ground water recharge to facilitate a more even distribution of ground water immediately north of the system.

The FY84 system evaluation report indicated the need to assess system components. This current evaluation report indicates the need to improve the distribution of ground water immediately north of the system. In response to the conclusions/recommendations generated in the above mentioned reports, the Program Manager for RMA Contamination Cleanup initiated study efforts during

1986 to support North Boundary interim response actions. The following specific interim response actions are in progress:

1. The design of an improved recnarge system (deep trench) for the west and central portions of the system; installation of this system is expected during the early fall of 1987.
2. A comprehensive assessment of the North Boundary System components (Task 36) to include these elements: the physical condition of the barrier, the geotechnical/hydrologic conditions of the Denver Sands immediately adjacent to the barrier, and the adequacies of the dewatering/recharge system; results of this assessment will provide data for an interim response action to upgrade the North Boundary System.

PREFACE

This study was conducted from October 1986 to March 1987 as part of a cooperative effort by personnel from the Program Manager Staff Office for Rocky Mountain Arsenal Contamination Cleanup (PMSO) and the U.S. Army Engineer Waterways Experiment Station (WES). Funding for participation by WES was provided by the Program Manager, Rocky Mountain Arsenal Cleanup via Intra-Army Order Nos. 87-D-2 and 87-D-3. Mr. E. Berry served as Project Coordinator for the PMSO. Project management was provided by Messrs. David W. Strang, PMSO, Norman R. Francingues, WES Environmental Laboratory (EL) and James H. May WES Geotechnical Laboratory (GL).

This study is part of a continuing assessment of the operational status of the North Boundary Containment/Treatment System at Rocky Mountain Arsenal (RMA). Previous work has been reported in the report entitled "North Boundary Containment/Treatment System Performance Report" Vols I and II, by Douglas W. Thompson, Edwin W. Berry, Brian L. Anderson, James H. May, and Richard L. Hunt, December 1985, that addressed the system operations during FY84.

The contributing authors to this report were Messrs. Edwin W. Berry, Brian L. Anderson and Jerry Barbieri, (PMSO), Douglas W. Thompson, Jack H. Dildine, Norman R. Francingues (WES-EL) and Paul Miller and William Murphy (WES-GL). The report was prepared under the direct supervision of Mr. David W. Strang (PMSO), Mr. Norman R. Francingues (WES-EL) and Mr. James H. May (WES-GL). The study and report were authorized by the Program Manager, Rocky Mountain Arsenal, COL Fernand A. Thomassy.

The authors acknowledge the support and assistance of the following people and organizations during this study: Mr. Roy Wade, Ms Darla McVann and Mr. Bennie Washington, WES, Mr. Jack Pantleo, Mr. Jim Clark and Ms. Dianna Reynolds, D. P. Associates and personnel of the Rocky Mountain Arsenal Information Center (RIC).

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows.

Multiply	By	To Obtain
acre	4046.873	square metres
cubic feet	0.02831685	cubic metres
feet	0.3048	metres
feet per mile (U. S. statute)	0.1893936	metres per kilometre
gallons (U. S. liquid)	3.785412	cubic decimetres
horsepower (550 foot-pounds (force) per second)	745.6999	watts
inches	2.54	centimetres
miles (U. S. statute)	1.609347	kilometres
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
square feet	0.09290304	square metres
square miles	2.589998	square kilometres

NORTH BOUNDARY CONTAINMENT/TREATMENT SYSTEM OPERATIONAL ASSESSMENT - FY85/86 ACTIVITIES

PART I: INTRODUCTION

Background

1. The North Boundary Containment/Treatment System* Operational Assessment described herein is the second in a series of reports prepared to document and evaluate the geochemical and hydrologic parameters and treatment process performance related to the boundary system operations. This report covers the operating periods of FY85 and FY86.

2. The report incorporates by reference major system descriptions and previous operations described in the report entitled "North Boundary Containment/Treatment System Performance Report" (Thompson et al. 1985). A chronology of events leading up to the expanded system construction, descriptions of detailed construction features, and geologic and hydrologic system descriptions is also described by Thompson et al. (1985). The reader is directed to the basic report for detailed information concerning the history and physical description of the system. The report is available for review at the Rocky Mountain Arsenal Information Center (RIC) library and is document number 86078R01.

Report Objectives

3. Report objectives include:

a. To assess the continuing effectiveness of the North Boundary System in preventing the offpost migration of contaminated ground water along the system alignment during eight time periods covering FY85 and FY86.

b. To document system operating parameters.

c. To identify and document system improvements, field studies, and facility alterations conducted during FY85 and FY86.

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* Hereinafter referred to as North Boundary System.

d. To identify and document operational improvements that will enhance long-term system effectiveness.

Approach

4. The approach to developing this study has been modified to incorporate direction of the office of the Program Manager, Rocky Mountain Arsenal Contamination Cleanup and the Program Manager Staff Office (PMSO) at Rocky Mountain Arsenal. The PMSO established and provided the reporting framework and objectives, the data base (Volume III) and general technical guidance. The Waterways Experiment Station, Vicksburg, Mississippi (WES) provided specialized Environmental Engineering and Geotechnical assessments.

5. The study was conducted in three phases. Originally, data were retrieved and organized by the PMSO and Rocky Mountain Arsenal Information Center (RIC). Next, WES and RMA personnel reviewed the data bases for completeness and then developed geotechnical and water quality assessments along with various system performance evaluations. During the course of study, several in-progress reviews and coordination working sessions were held at RMA and WES to facilitate exchange of information and to assure continuity and consistency in data interpretations and evaluations. Finally, the report was assembled from individual sections prepared by the various contributing authors.

Organization of Report

6. This report consists of three volumes. Volume I is the main text and consists of six parts. Following this introductory part are five parts dealing with data collection, system operations including facility alterations and modifications, data evaluations for geologic, hydrologic and treatment systems, an assessment of system effectiveness, and finally, conclusions and recommendations. Volume II contains all of the plates referred to in Volume I. The data bases developed to support the evaluations and assessments made during the study are located in Volume III. Volume III will not be distributed with Volumes I and II. Instead, it will be maintained on file at the RIC reference library at Rocky Mountain Arsenal.

PART II: DATA COLLECTION

Ground Water Monitoring

Background

7. The ground water monitoring programs conducted at the North Boundary System during FY85-86 consisted of the collection of water quality and water level data. The FY85 ground water monitoring program was conducted by the Rocky Mountain Arsenal, Technical Operations Directorate, Environmental Division. The FY86 monitoring program was conducted by the Program Manager, Rocky Mountain Arsenal Contamination Cleanup (PM, RMA) as part of remedial studies being conducted at RMA. The development of the monitoring task technical plans for Task 4, Task 6, and Task 25 and the implementation of the monitoring programs was performed for the PM, RMA under the direction of Environmental Sciences and Engineering, Inc., the task contractor.

FY85 Monitoring Program

8. The FY85 ground water monitoring program was a continuation of the previous years boundary system monitoring program. Changes to the monitoring program, especially in the number of Denver Formation wells to be monitored, were made in response to the recommendations made in the 1984 North Boundary Report (Thompson et al. 1985).

9. The RMA ground water monitoring program utilized 77 well sites for quarterly water quality sampling during FY85 as compared to 60 sites during FY84. Fifty eight (58) of the sites were alluvial wells and 19 sites monitored Denver Formation sand units. Quarterly water level measurements were collected from these sites, as well as an additional 113 alluvial and Denver sites in the study area. The sampling protocol used for this monitoring effort was the same procedure used for the FY84 monitoring program. The sampling protocol is presented in Appendix A of the 1984 North Boundary Containment/Treatment System Performance Report (Thompson et al. 1985).

10. The field program of water sample collection and water level data collection was performed by the RMA Environmental Division, Compliance and Resources Branch. The water samples were submitted to the RMA Environmental Division Laboratory for the analysis of DIMP, DBCP, DCPD, the chlorinated

pesticides; endrin, isodrin, aldrin and deieildrin; the sulfur compounds oxathiane, dithiane, sulphone, sulfoxide, sulfide; chloride, and fluoride. Four sets of water quality and water level data for the four quarters of FY85 were developed.

FY86 Monitoring Program

11. The FY86 ground water monitoring program was conducted as part of the PM, RMA remedial program activities at the Arsenal, also involved the collection of water quality and water level data. In addition to the PM, RMA monitoring program, the RMA Technical Operations Directorate also collected some water level and water quality data from the study area during the 1st quarter of FY86. These data were collected using the same procedures as the FY85 program described above. The data that were collected for the North Boundary System monitoring, under the PM, RMA program, were produced by three separate PM, RMA tasks: Task 4 "RMA Water Quantity/Quality Survey," Task Order 6 "Offpost Contamination Assessment" and Task 25 "Boundary Systems Monitoring." Changes in the monitoring program for the North Boundary System were incorporated in the FY86 program to address further the recommendations made by Thompson et al. (1985).

12. The basic ground water monitoring program for the PM, RMA is the regional program, that consists of the RMA Water Quantity/Quality Survey and the Off-post Contamination Assessment. These programs were initiated at the beginning of FY86 and consisted of monitoring the water quality at 363 alluvial and Denver Formation sites. Of these sites 43 were located off-post. Water level data were also collected at 863 alluvial and Denver Formation wells located both on-post and off-post. Out of this regional monitoring effort, 44 sites consisting of 33 alluvial and 11 Denver wells were monitored for water quality in the North Boundary System study area. Water level data from 184 alluvial and Denver sites were also collected in the study area both on-post and off-post. During the last quarter of FY86, the Boundary Systems Monitoring Task (Task 25), was initiated to provide detail site specific data for the operating systems. This monitoring task consolidated all efforts of water quality sampling and water level data collection in the North Boundary System area. The task collected 131 samples from 100 alluvial and 31 Denver Formation wells for analysis. Water levels were collected at 263 alluvial and Denver Formation sites. All monitoring for Task 25 was conducted in Sections 23 and 24 on-post and Sections 13 and 14 off-post.

13. The tasks utilize the same protocols, that were developed specifically for the investigative program for RMA. The sampling and data collection protocols are presented in the Task 4 and Task 25 technical plans. These documents are available for review at the RIC Center located at RMA under document numbers 87013R01 and 87014R24, respectively.

14. The Task 25 monitoring program was conducted by Environmental Science and Engineering, Inc. (ESE) and their subcontractors. Water samples were submitted to the ESE laboratories located in Gainsville, Florida and Denver, Colorado for the analysis of the contaminants listed in Table 1. The analytical methods used for each analysis are also identified on Table 1. Four sets of water quality and water level data for the four quarters of FY86 were produced.

15. Data Management. The sample analysis and water level data for the North Boundary System are maintained on the PM, RMA computer system and the RIC computer. Laboratory and field data were entered into the data base by the RIC or the task contractors, subjected to the data check routine, validated and placed into the PM, RMA data base. Data sets were prepared and then used to construct data tables, maps, graphs, etc. Volume III of this report contains a copy of the water quality and water level data that were used in this report. The data can also be obtained through the RIC at Rocky Mountain Arsenal or the PM, RMA computer system located at Aberdeen Proving Ground, Edgewood Area, Maryland.

Plant Operations Monitoring

16. The treatment plant monitoring program included collection of data on flow quantities through the system and on the quality of the water entering and leaving the plant. The flow quantities were obtained from individual totalizing flow meters located upstream of each adsorber and on the combined effluent stream. The meters were read and the values recorded on a daily basis in the plant operations log. Weekly flow quantities were calculated from the daily reports. Weekly flow rates were calculated by dividing the total flow for the week by 10,080 minutes per week. Flow rates for the dewatering and recharge wells were obtained from individual flow meters that were relocated into Building 808 (the treatment plant building) during FY85.

Table 1

Chemical Analysis - Task 25

Analysis/Analytes	Maximum Hold Time	Level of Certification	Reference Methods	Method
Organochlorine Pesticides		Quantitative	EPA 608	CAP-GC/ECD
Aldrin Endrin Dieldrin Isodrin Hexachlorocyclopentadiene p,p'-DDE p,p'-DDE Chlordane	Extract as quickly as possible. (No more than 7 days). Analyze within 40 days of extraction.			
Volatile Organohalogens		Quantitative	EPA 601	PACK-GC/Hall
Chlorobenzene	14 days			
Chloroform	14 days			
Carbon Tetrachloride	14 days			
trans-1,2-Dichloroethylene	14 days			
Trichloroethylene (TCE)	14 days			
Tetrachloroethylene	14 days			
1,1 Dichloroethylene	14 days			
1,1 Dichloroethane	14 days			
1,2 Dichloroethane	14 days			
1,1,1 Trichloroethane	14 days			
1,1,2 Trichloroethane	14 days			
Methylene Chloride	14 days			
Organosulfur Compounds		Quantitative		PACK-GC/FPD-S
P-Chlorophenylmethylsulfone ($PCPMSO_2$) P-Chlorophenylmethylsulfoxide (PCPMSO) P-Chlorophenylmethylsulfide (PCPMS) 1,4-Dithiane 1,4-Oxathiane Dimethyldisulfide (DMDS)	Extract as quickly as possible. (No more than 7 days). Analyze within 40 days of extraction.			

(Continued)

Table 1 (Concluded)

Analysis/Analytes	Maximum Hold Time	Level of Certification	Reference Methods	Method
DCPD/MIBK		Quantitative	EPA 608	CAP-GC/FID
Dicyclopentadiene/ Methylisobutylketone	Extract as quickly as possible. (No more than 7 days). Analyze extract within 40 days of extraction.			
DIMP/DMMP		Qualitative	EPA 622	PACK-GC/FPD-P
Diisopropylmethylphosphonate/ Dimethylmethylphosphonate	Analyze within 47 days of sampling.			
DBCP		Quantitative		CAP-GC/ECD
Dibromochloropropane	14 days			
Inorganics		Quantitative		
Arsenic	6 months		EPA 206	AA-Hydride Furnace
Chloride	28 days		EPA 300	Ion Chromatograph
Fluoride	28 days			
Sulfate	28 days			
Volatile Aromatics		Quantitative	EPA 602	PACK-GC/PID
Toluene	14 days			
Benzene	14 days			
Xylene (o-, m-, p-)	14 days			
Ethylbenzene	14 days			

Source: ESE, 1985.

17. Samples are taken weekly from the interior of the adsorbers for process control. These data are used in determining when to change carbon within the adsorber which is done on a batch basis. The quality of the plant's influent and effluent was monitored by taking water samples on a weekly basis and analyzing them. Influent samples were collected from each of the three individual carbon adsorber influent lines from sampling ports located between the pre-filters and the adsorbers. A composite effluent sample was collected from a sampling port upstream of the post-filters. Influent and effluent samples were collected on weekly basis. Samples were collected also from the dewatering wells on a quarterly basis. These samples were collected from ports located in the well houses.

18. All water samples were collected in previously cleaned, glass containers, sealed, and transported to the analytical laboratory at RMA for analysis. The parameters for which the plant samples were analyzed for during FY85 and FY86 are presented in Table 2. All analyses were performed using standard methods. The sample analysis and flow data were entered into the analytical data base by laboratory personnel, subjected to a quality control routine, validated, and placed into the PM, RMA data base by the RIC. Data sets were prepared for use in developing tables and figures. Copies of the plant analytical and flow data for FY85 and FY86 are contained in Volume III of this report.

Table 2

Chemical Analysis of Treatment Plant Samples

Analyte	FY85	FY86
Aldrin	X	X
Chloride	X	X
P-Chlorophenylmethylsulfide	X	X
P-Chlorophenylmethylsulfoxide	X	X
P-Chlorophenylmethylsulfone	X	X
Dibromochloropropane	X	X
Dicyclopentadiene	X	X
Diisopropylmethylphosphonate	X	X
Dithiane	X	X
Dieldrin	X	X
Endrin	X	X
Fluoride	X	X
Hardness	X	
Isodrin	X	X
Oxathiane	X	X
pH	X	
TOC	X	

PART III: SYSTEM OPERATIONS AND FACILITY ALTERATIONS

Operational Summary

19. A log of plant operations for the North Boundary system is maintained by RMA plant operations personnel with major events documented on a daily basis. The log contains comments on the operation, maintenance, and repair of the dewatering and recharge wells, pipes, electrical components, sumps, and treatment equipment. The log notes various problems during FY85 that significantly affected the normal operation of the system. These problems included electrical power outages, equipment malfunctions, pipe breakages, and wells plugging. Normal operation of the system was also impacted by scheduled maintenance and repair activities. A major alteration and repair project was conducted during the first three quarters of FY85. Plant operations were limited during this period due to new construction and equipment modification.

20. Downtime due to equipment failures was reduced in FY86 as a result of the FY85 alteration and repair project. Some equipment failures and electrical power outages were reported. Overall plant operations were affected during the first two quarters of FY86 by a maintenance project involving the cleaning of the dewatering/recharge well subsystem. The individual wells were taken off-line during the cleaning procedure. This action resulted in some reduction in overall system flow rates.

Alterations and Repairs

21. The majority of the alterations and repairs conducted during FY85 were included in the North Boundary Alteration and Repair Project that was initiated in Oct 1984 and continued through June 1985. This project incorporated many of the modifications previously recommended to reduce mechanical problems occurring in the system (Thompson et al. 1985). The major modifications conducted during the project are as follows:

a. Relocation of the dewatering and recharge well flow meters into Building 808. This modification involved removing the battery operated flow meters from the well houses and replacing them with more reliable AC powered meters in Building 808. The potential for the meters to freeze and break was eliminated. In addition, the time required to read the meters was reduced from hours to minutes.

b. Winterization of the well houses. This modification included the insulation of the well houses, removal of the pipe heat tape, and installation of a heater in each well house. The potential for freezing of the pipes and valves in the well houses has been significantly reduced.

c. Installation of additional shut-off valves in the underground piping network. This modification provides flexibility in system operation when pipe breaks occur. It is now possible to isolate the broken line or well segment for repair without shutting down the entire well system.

d. Rework and cleaning of the recharge wells. This activity included physical cleaning of well casings and screens and surging of the wells to remove carbon fines from the adsorbers that tended to plug the recharge wells. Cleaning of the wells helps to regain some of their original recharge capacity.

e. Addition of an effluent flow meter. A flow meter was installed in the plant effluent line going to the recharge wells. This allows for periodic checks on the overall flow from the treatment plant.

22. The majority of the alterations and repairs conducted during FY86 were aimed at eliminating the problem of carbon fines migration from the adsorbers into the recharge well subsystem. A cleaning program was conducted during the period October 1985 through April 1986. The program included cleaning and flushing of the recharge manifold and recharge wells, and surging of the recharge wells. Also during this program, the dewatering wells were cleaned and surged. During the period May 1986 through June 1986, stiffeners were installed in the treatment plant cartridge filters holders through which the effluent passes on its way to the recharge wells. These stiffeners help keep the filter cartridges seated firmly, thus, inhibiting the migration of carbon fines around the ends of the filter cartridges.

System Flow Quantities

23. The quantity of flow through the treatment system is recorded on a daily basis. The flow quantities recorded for FY85 and FY86 are presented in tabular form in Volume III, Part I of this report. Graphs of weekly flow data for each adsorber and the effluent stream have been prepared and are presented

in Figures 1 through 8. The Treatment Plant flow data was accumulated on a weekly (7 day) basis beginning with the first day of the FY and continuing to the end of the FY. Thus, each bar on the flow graphs represents data for one week. This graphical presentation may cause some confusion with the monthly labels on the graphs. The months are only a guide to show approximately where the weekly flows would fall in relation to the months.

24. During FY85, total flow (effluent) quantities ranged from a low of 0 gpm to a high of approximately 340 gpm. The plant was shut down during December 1984 for repair. Flow quantities fluctuated during the rest of FY85 due to periodic interruptions in operation as a result of the Alteration and Repairs Project, power outages, and mechanical failures. Average flow rates and total gallons of water treated during FY85 are presented in Table 3.

Table 3

FY85 System Flow Quantities

Adsorber	Average Flow Rate (gpm)	Total Volume Treated (gal)
A	68.25	35,866,200
B	86.06	45,224,100
C	71.41	37,528,900
Total Effluent	225.72	118,619,200

The total volume treated for FY85 was approximately 8.3 million gallons higher than that treated for FY84. The average flow rate in FY85 was approximately 15 gpm higher than for FY84.

25. During FY86, total flow rate (effluent) ranged from a low of approximately 60 gpm to a high of approximately 320 gpm. The low flow rate in January 1986 resulted from the interruption of operations due to the well cleaning program. The low flow in April 1986 resulted from a power outage due to a spring blizzard. Average flow rates and total gallons of water treated during FY86 are presented in Table 4. The total volume treated for FY86 was approximately 7.6 million gallons higher than that treated for FY85. The average flow rate in FY86 was approximately 14 gpm higher than for FY85.

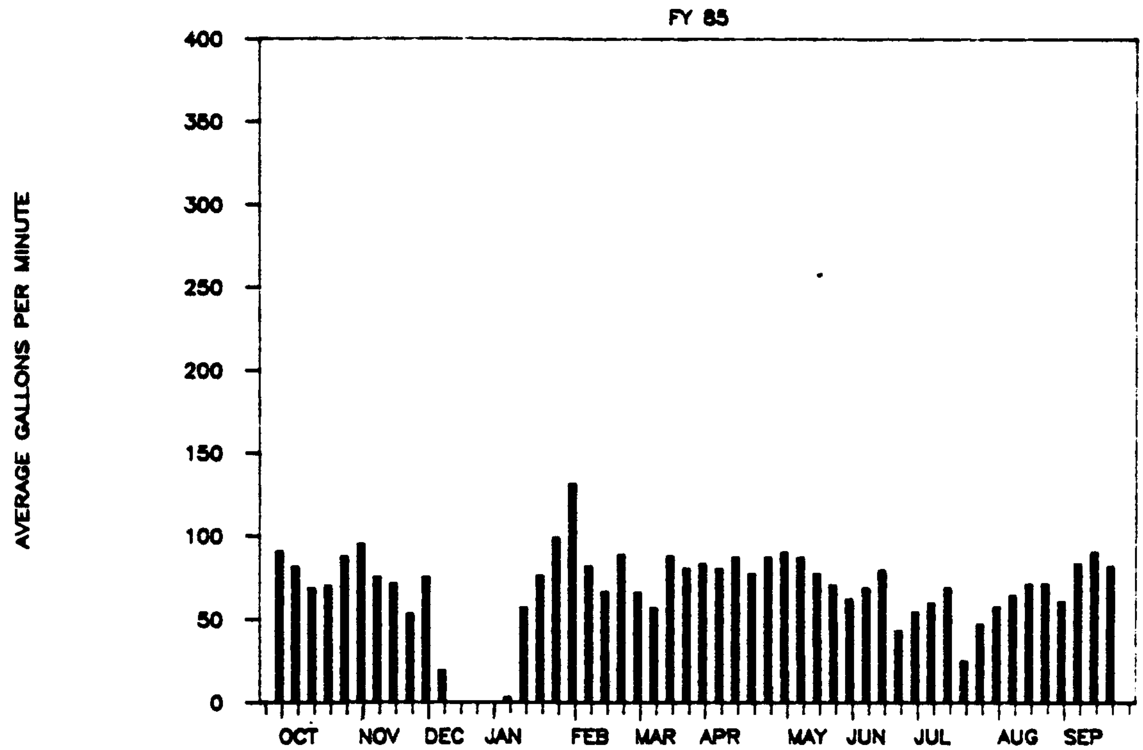


Figure 1. Adsorber A flow rate during FY85

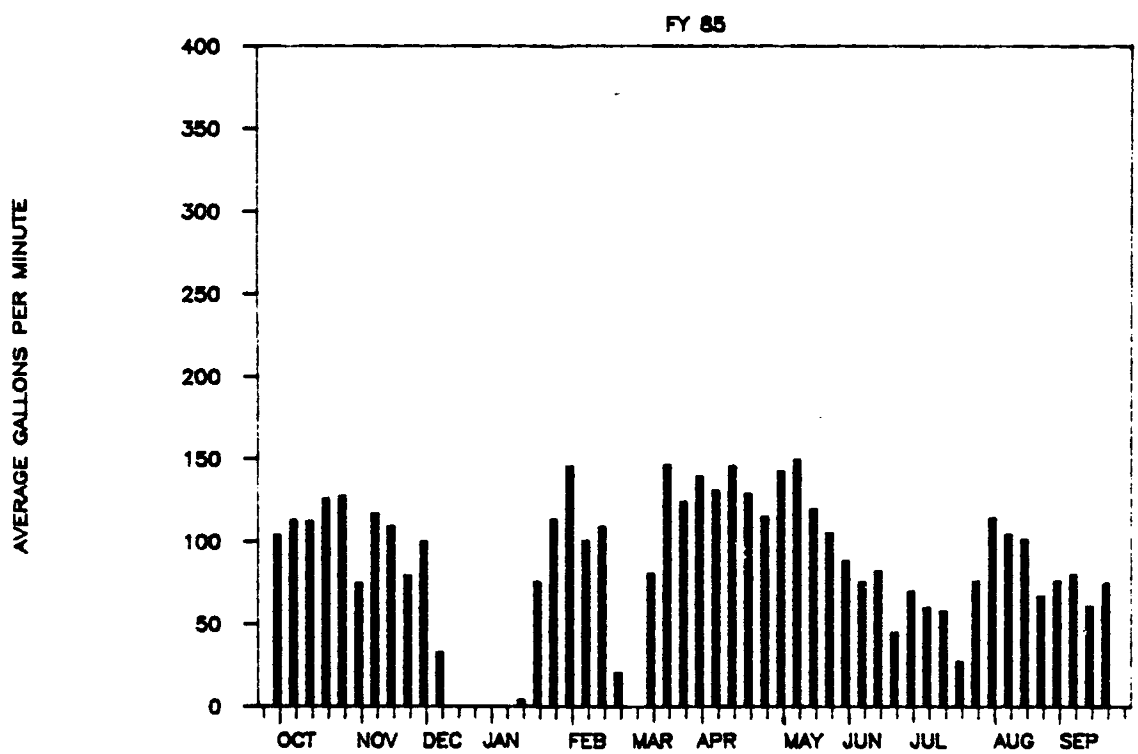


Figure 2. Adsorber B flow rate during FY85

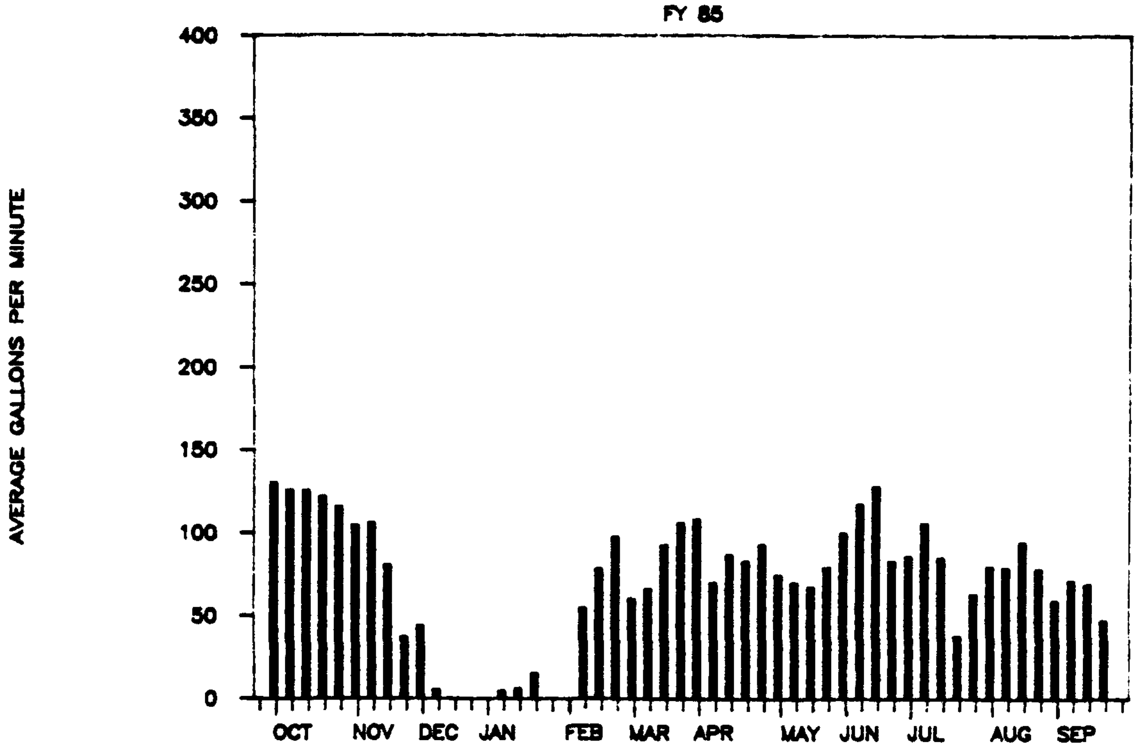


Figure 3. Adsorber C flow rate during FY85

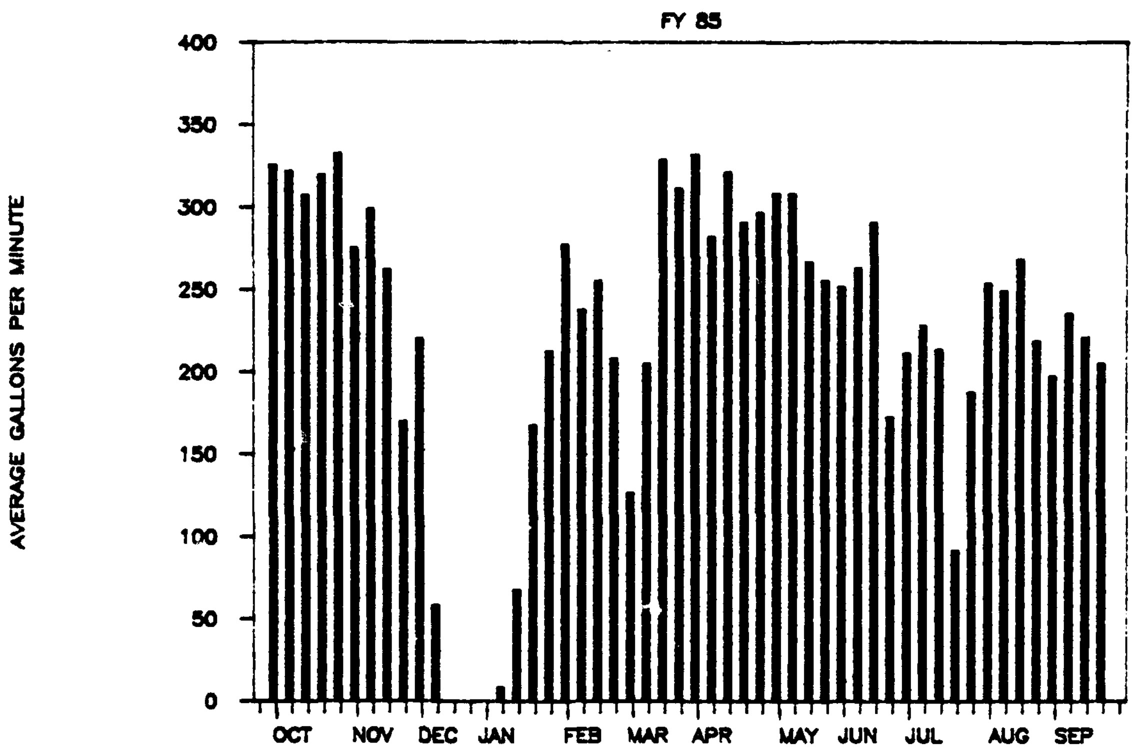


Figure 4. Effluent flow rate during FY85

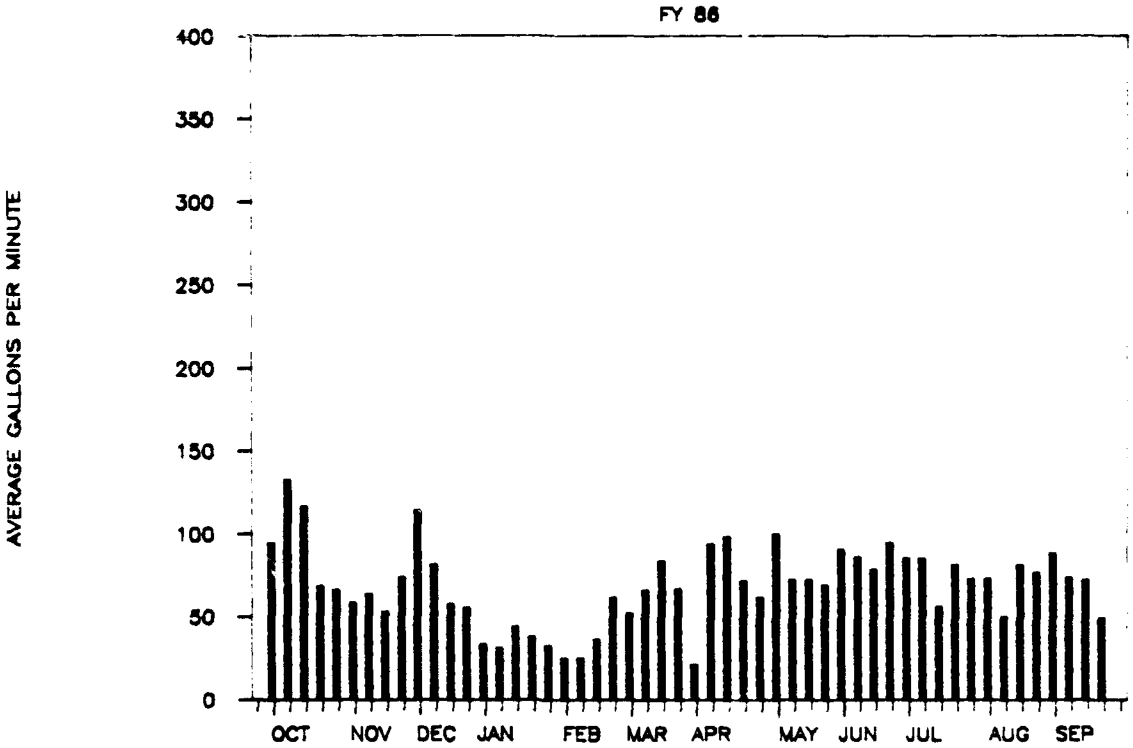


Figure 5. Adsorber A flow rate during FY86

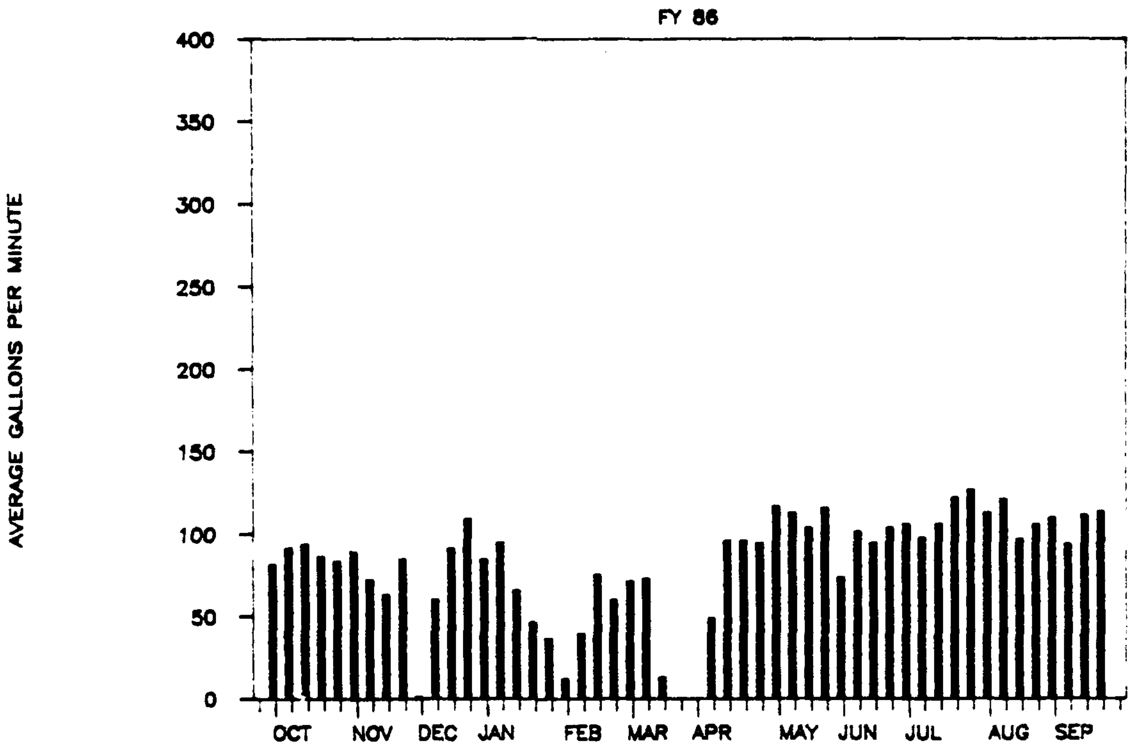


Figure 6. Adsorber B flow rate during FY86

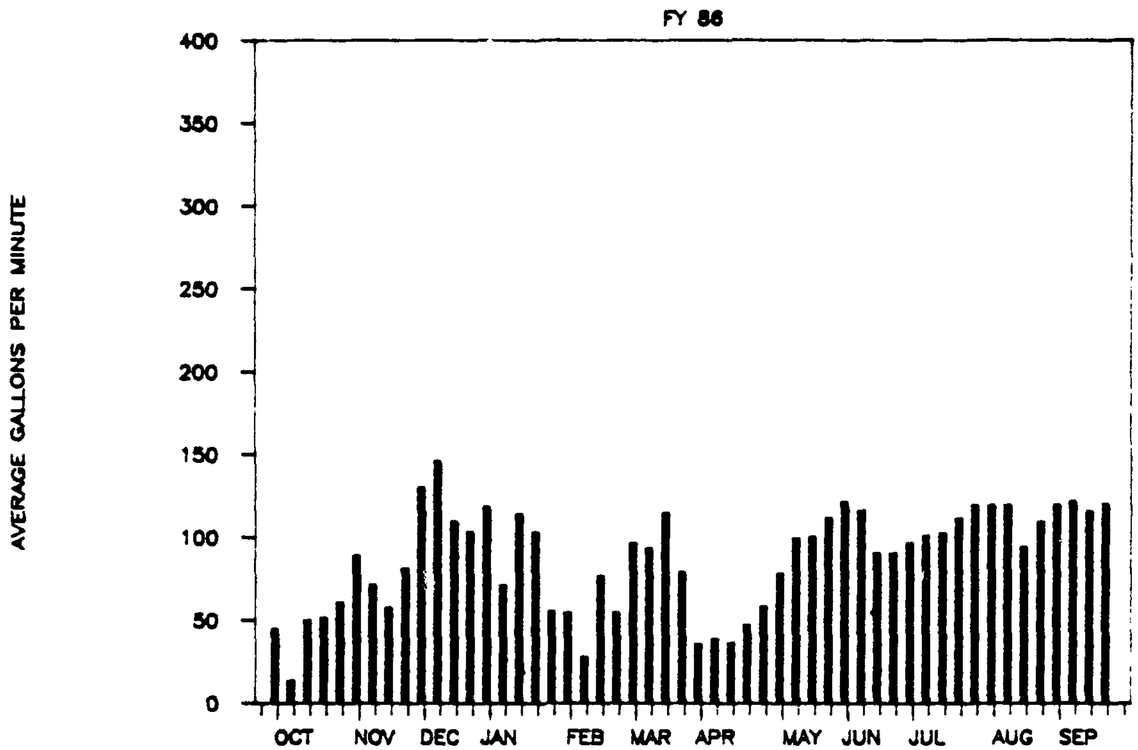


Figure 7. Adsorber C flow rate during FY86

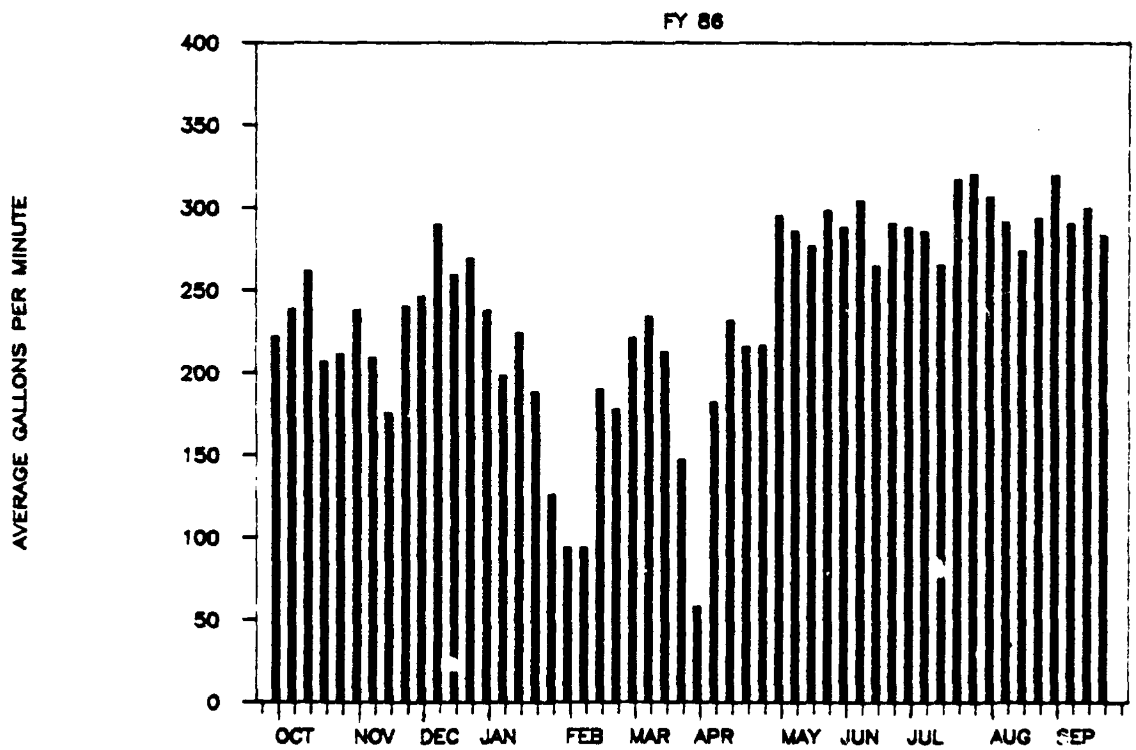


Figure 8. Effluent [illegible] rate during FY86

Table 4

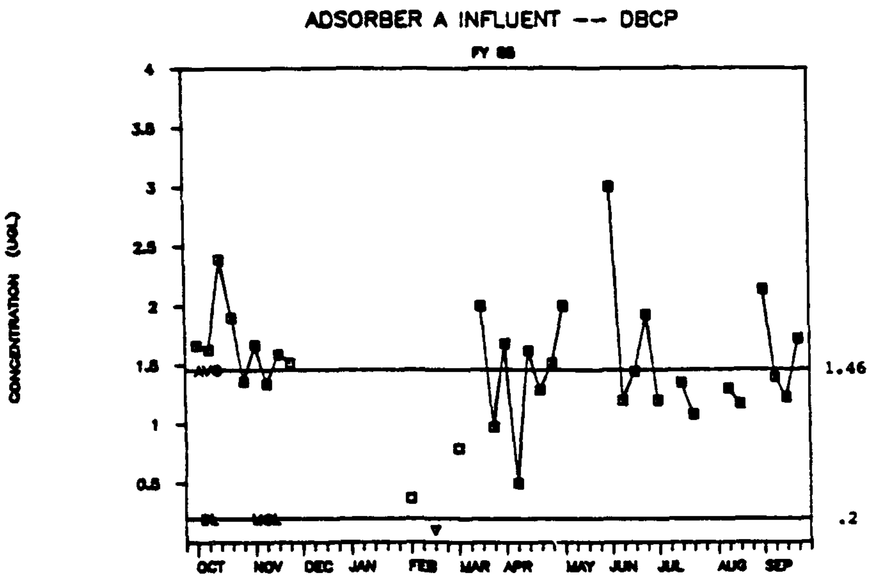
FY86 System Flow Quantities

Adsorber	Average Flow Rate (gpm)	Total Volume Treated (gal)
A	69.52	36,539,500
B	82.44	43,335,200
C	88.18	46,351,400
Total Effluent	240.14	126,226,100

System Influent and Effluent Water Quality

26. The quality of the influent and effluent from the treatment system is monitored periodically by taking grab samples and analyzing them for the contaminants of concern. Influent samples are collected from each of the three individual adsorber treatment units in order to determine the quality of water flowing to each adsorber. Samples are collected at the outlet of each adsorber to determine adsorber effectiveness and at the influent of the post filters to determine plant effluent water quality.

27. The results of these analyses, except for the adsorber effluent values, which are maintained in the RIC separately, for the period October 1984 through September 1986 are presented in tabular form in Volume III, Part II of this report. Graphs of the concentrations found for DBCP, DIMP, DCPD, combined organo-sulfurs, aldrin, endrin, dieldrin, chloride, and fluoride over this period have been prepared and are presented in Figures 9 through 26. A separate figure for each adsorber and the plant effluent for FY85 and FY86 has been prepared. Each figure contains a plot of the contaminant concentrations found over the particular FY and three lines indicating the detectable limit, the maximum operating limit (MOL) permitted (criteria), and the average concentration over the FY where sufficient data was available to calculate an



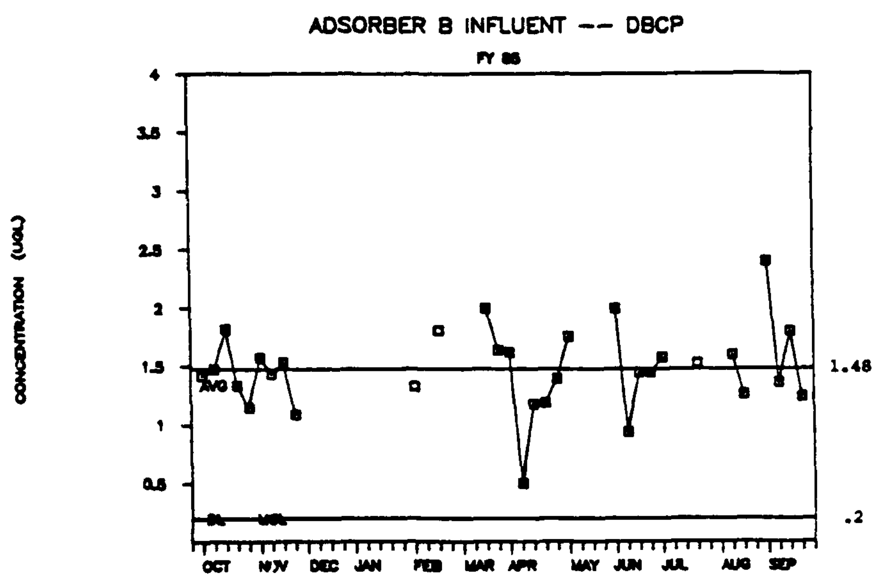
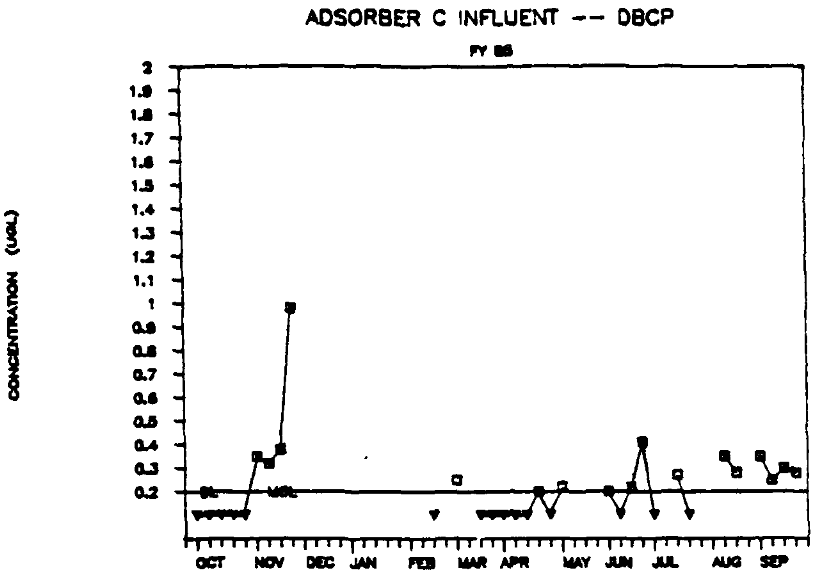


Figure 9. FY85 DBCP (Continued)



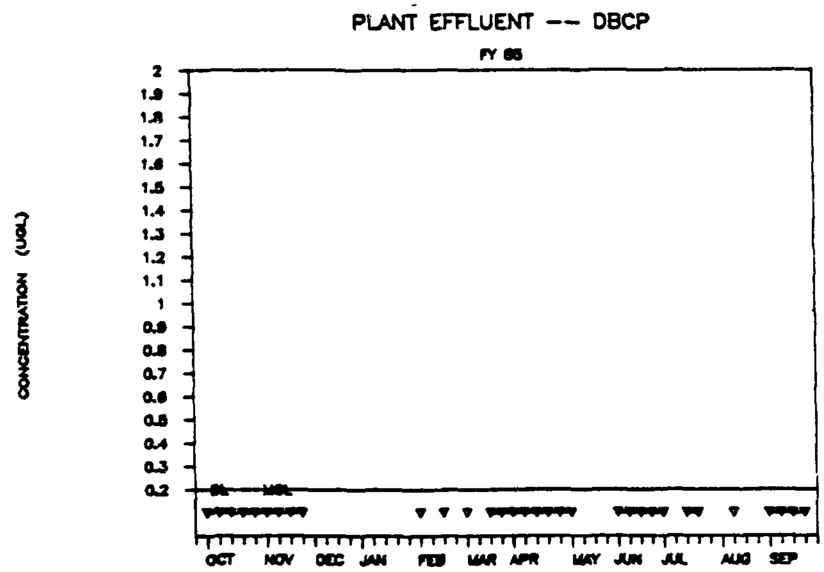
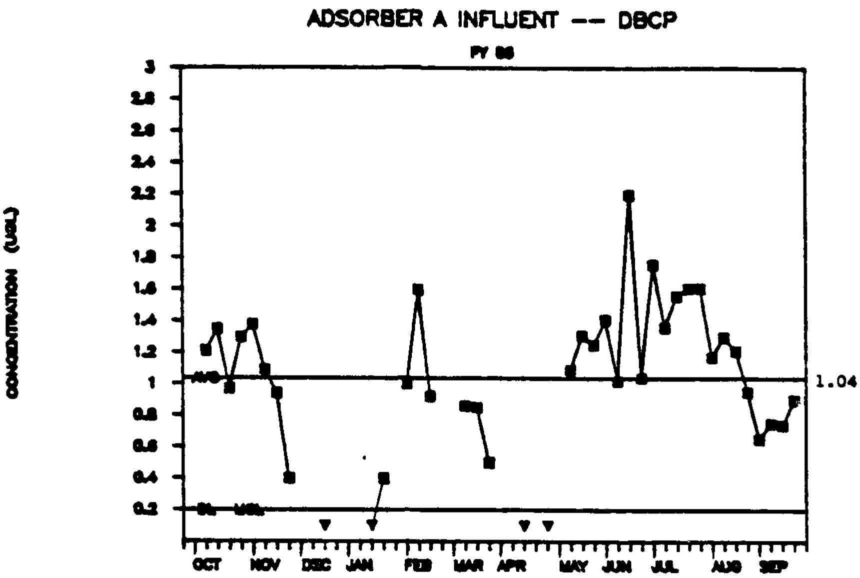


Figure 9. (Concluded)



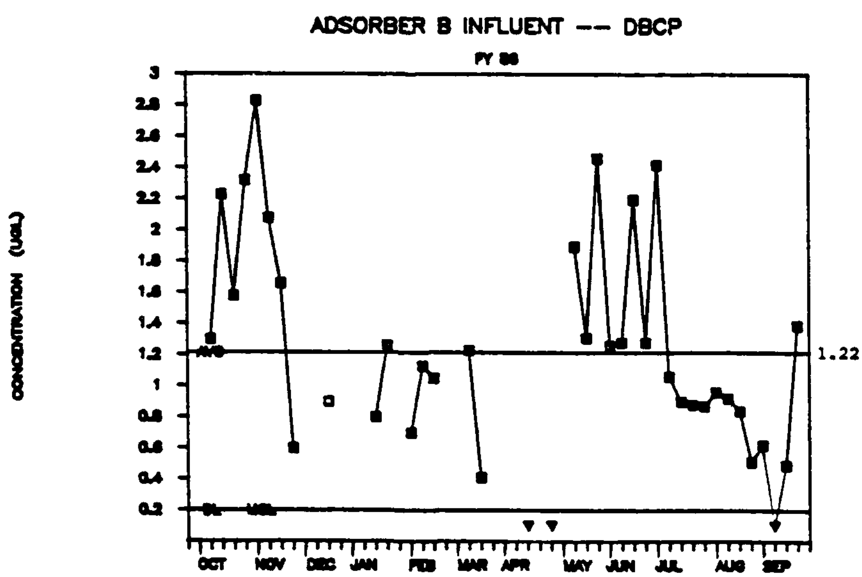
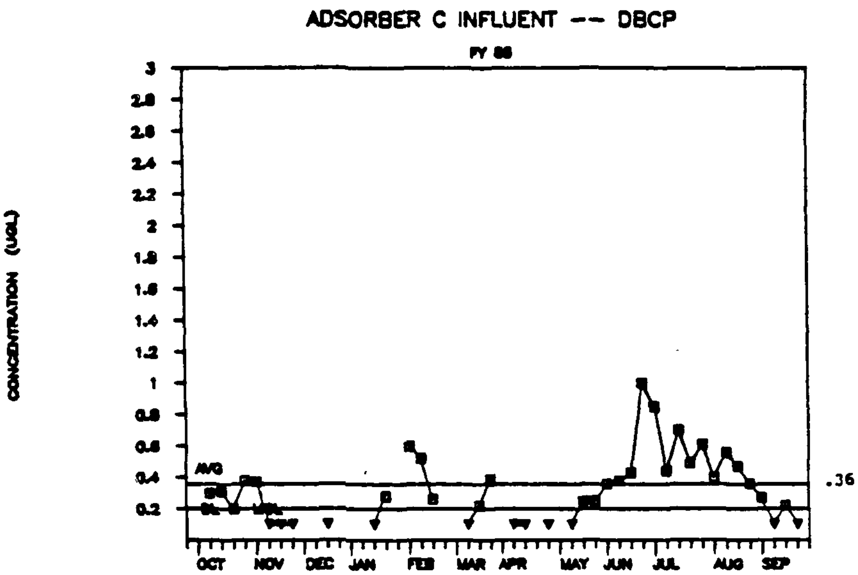
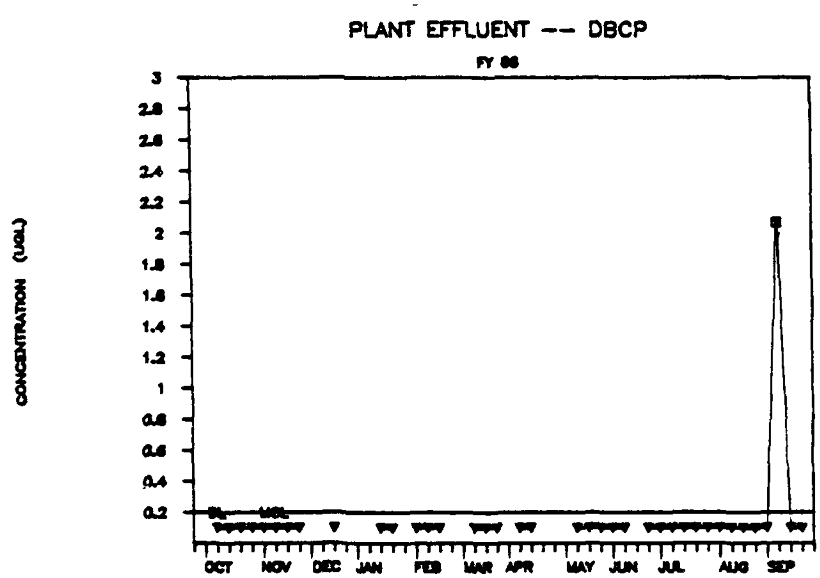


Figure 10. FY86 DBCP (Continued)





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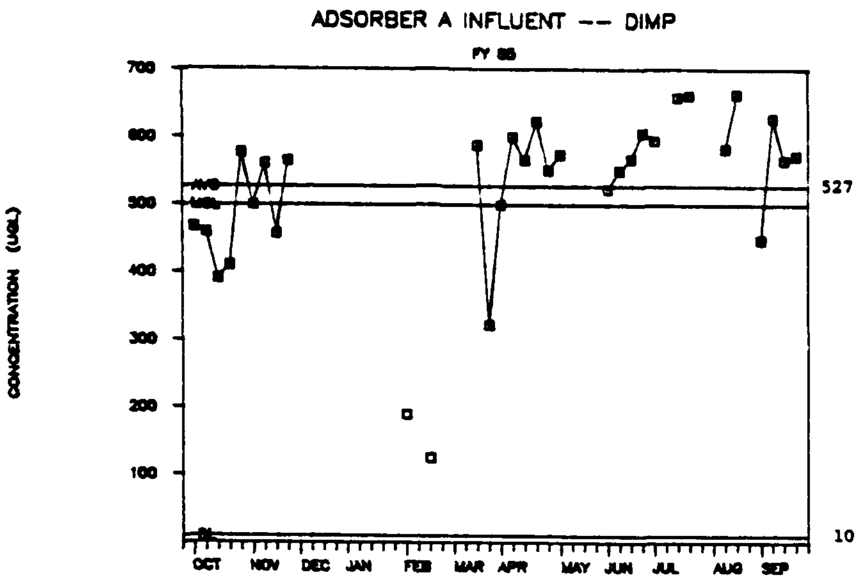


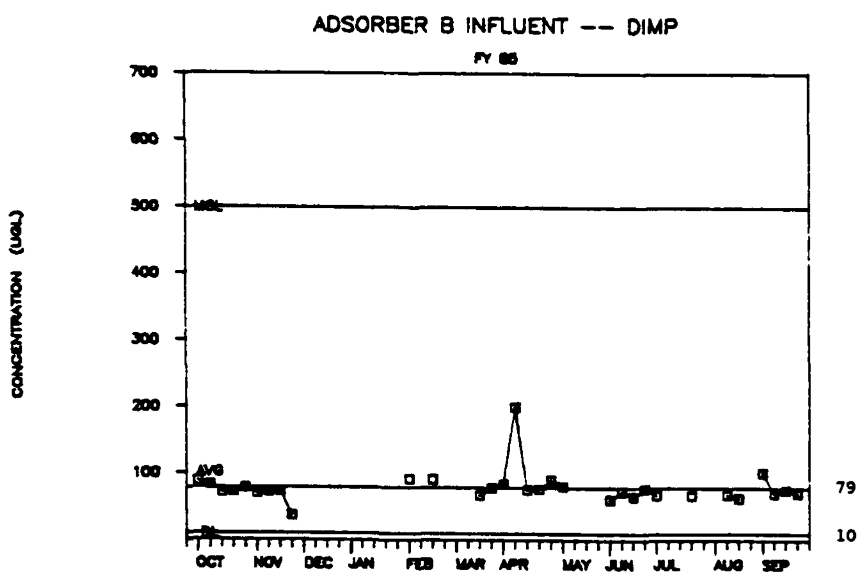
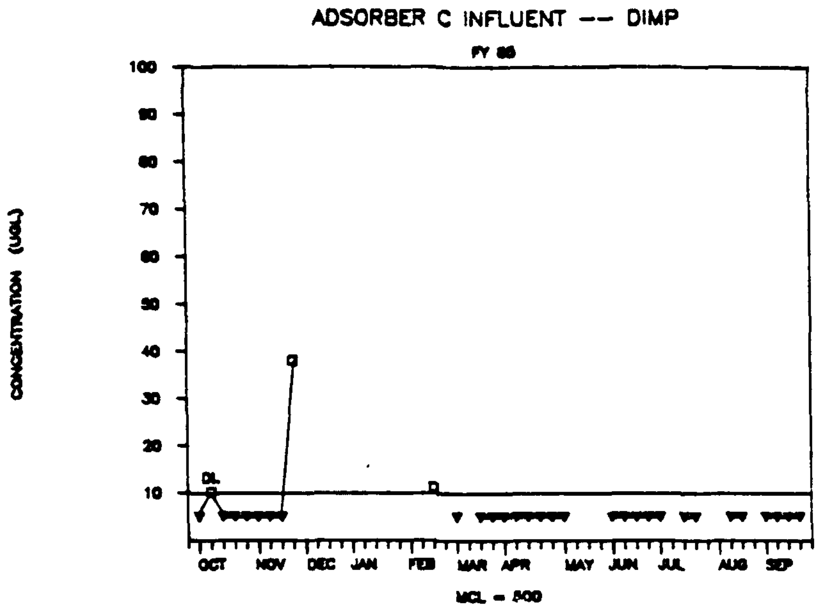
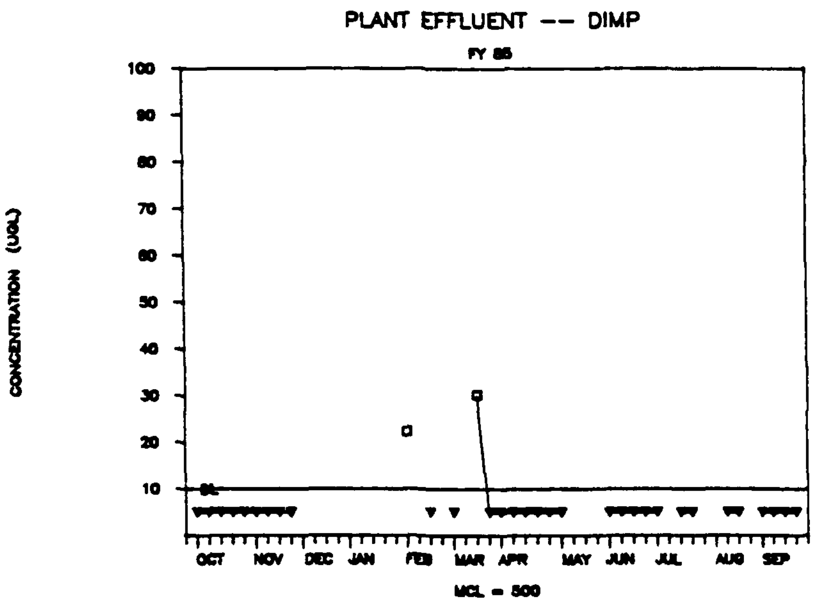


Figure 11. FY85 DIMP (Continued)





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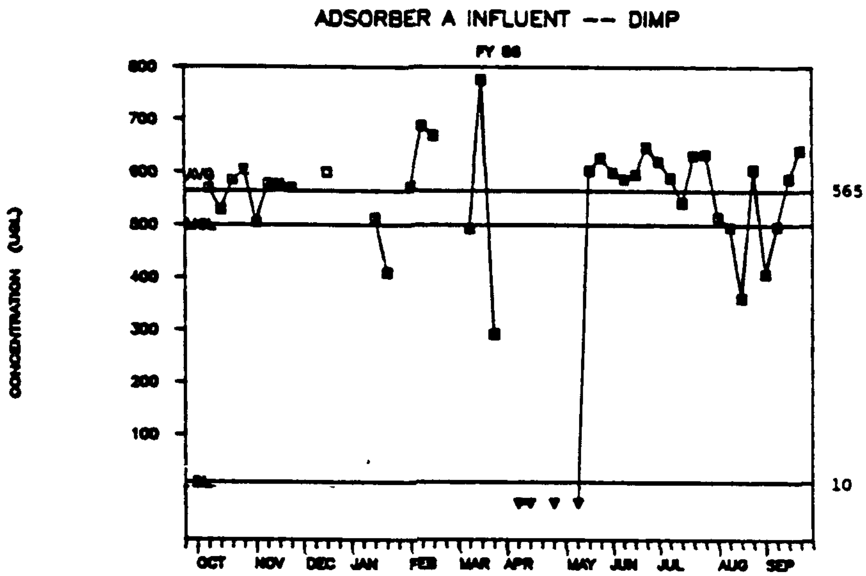


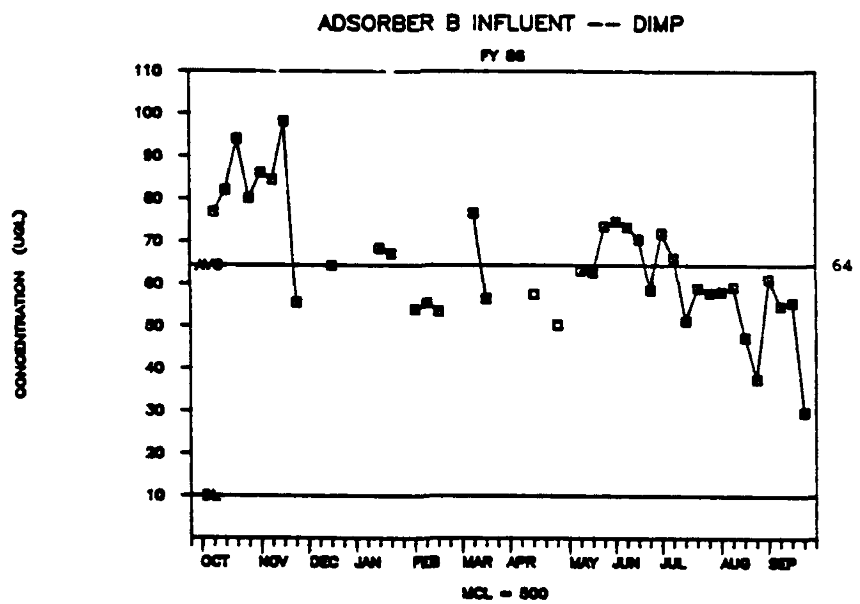
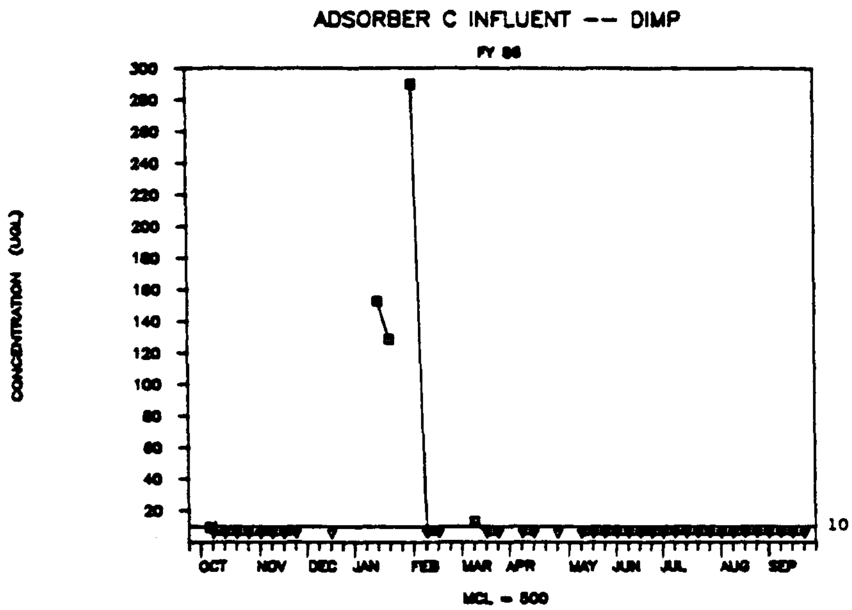
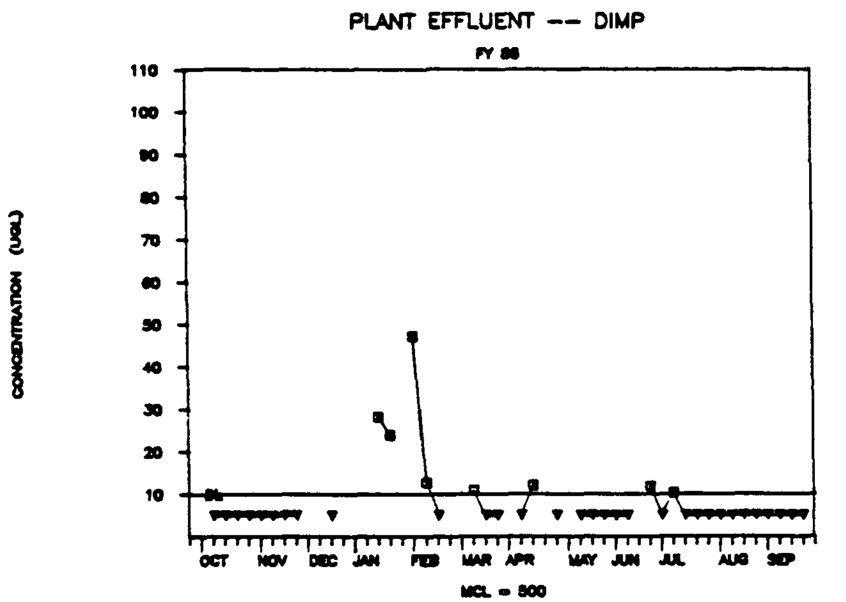


Figure 12. FY86 DIMP (Continued)





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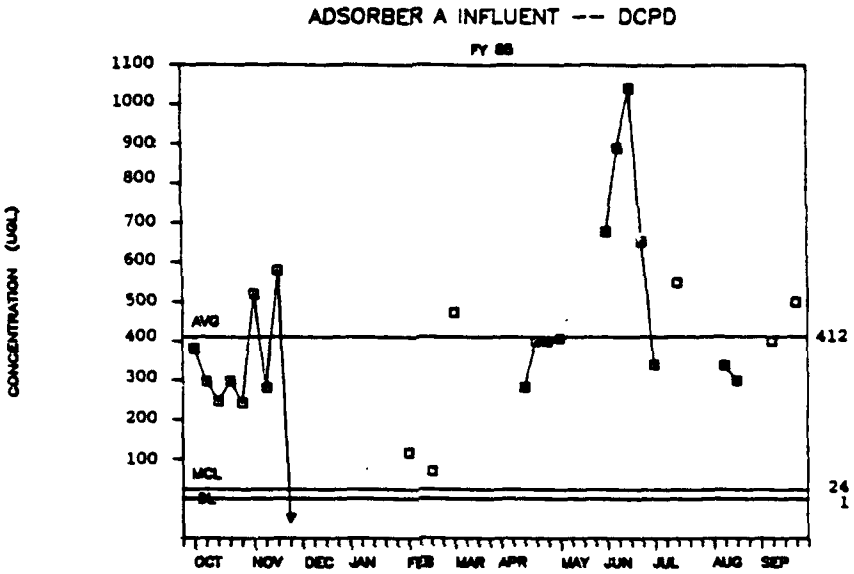


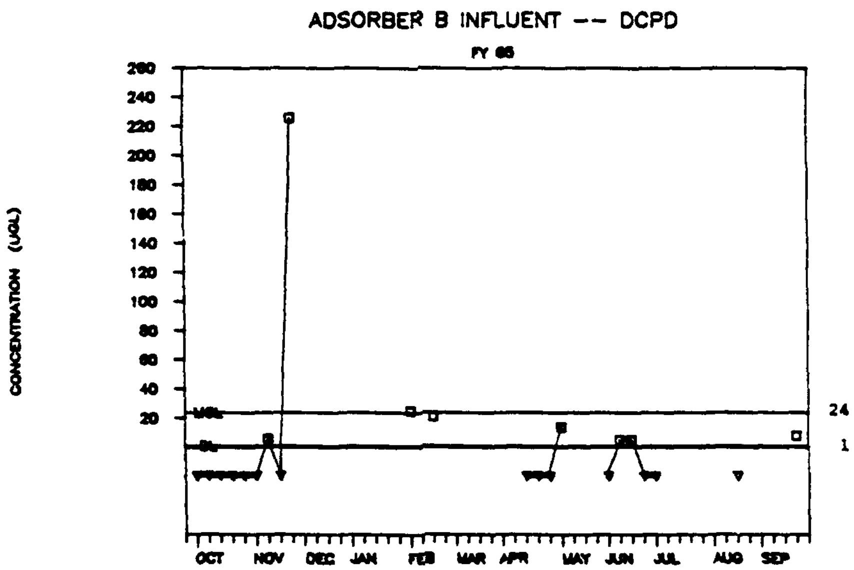
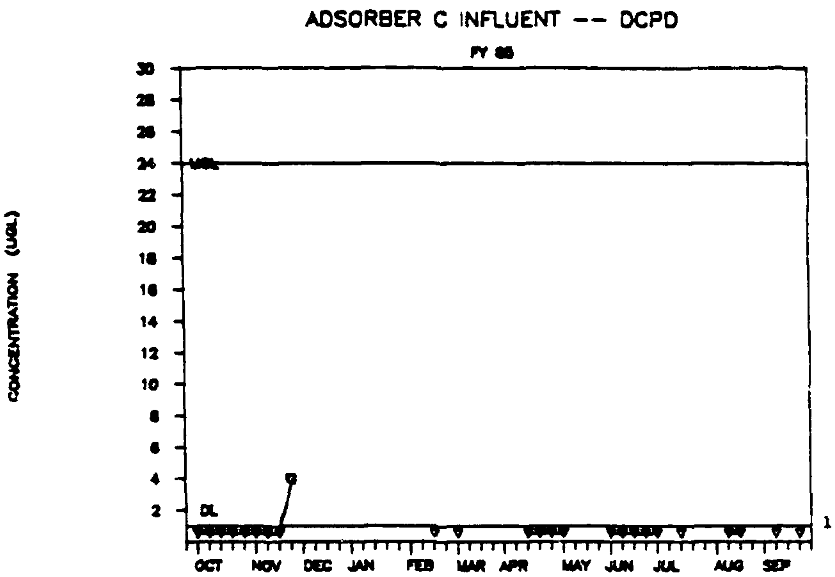
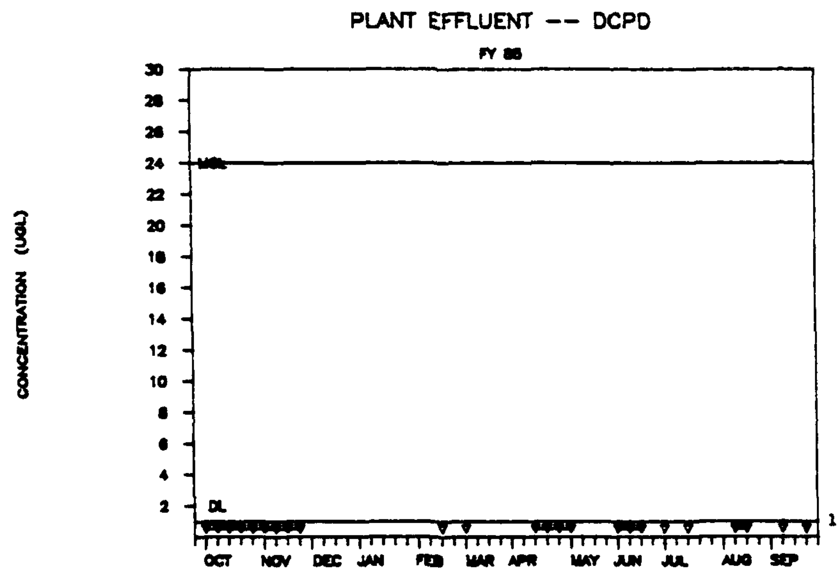


Figure 13. FY85 DCPD (Continued)





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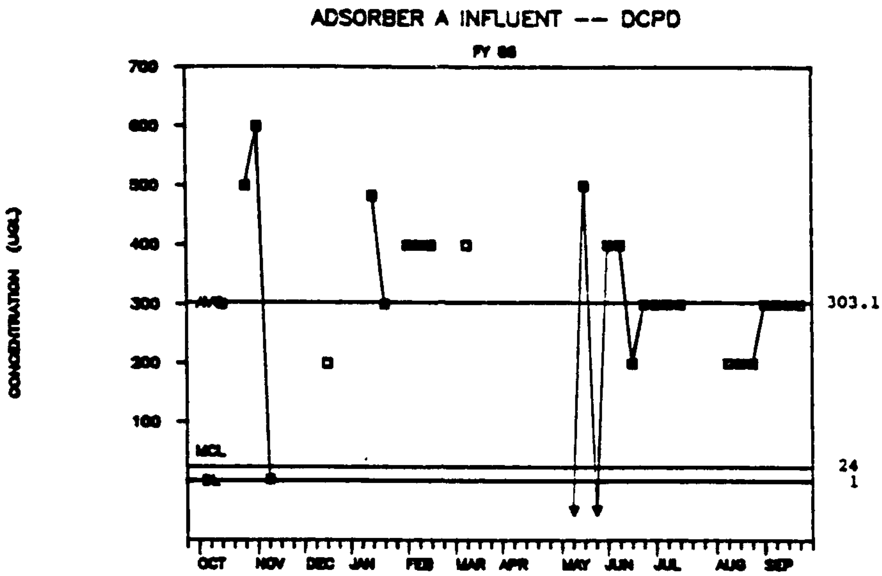


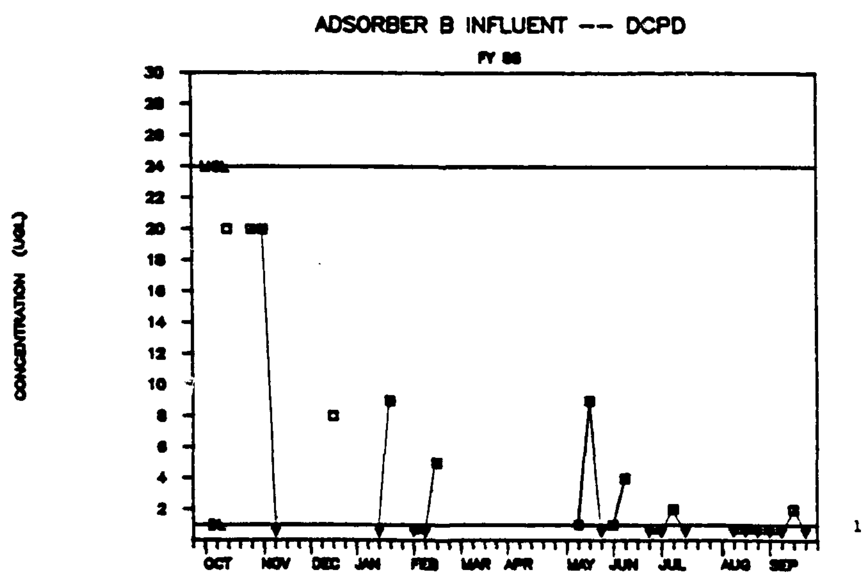
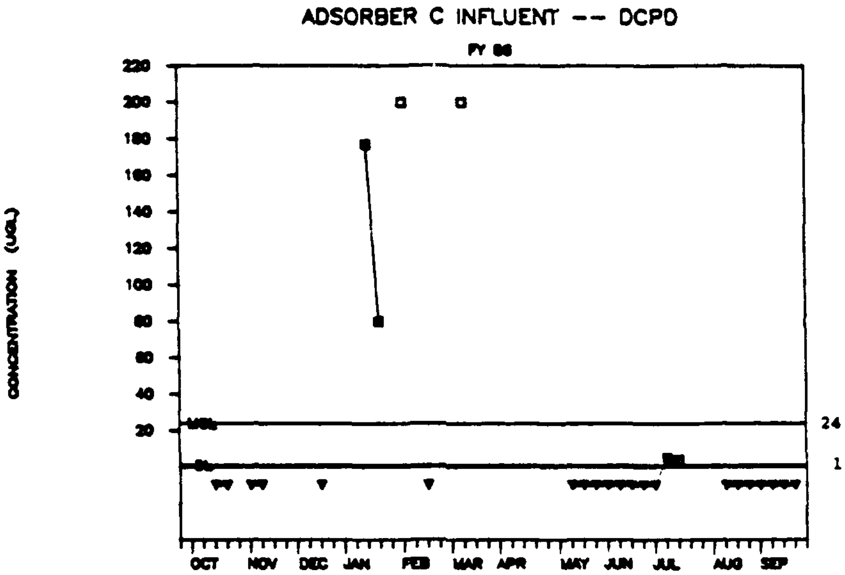
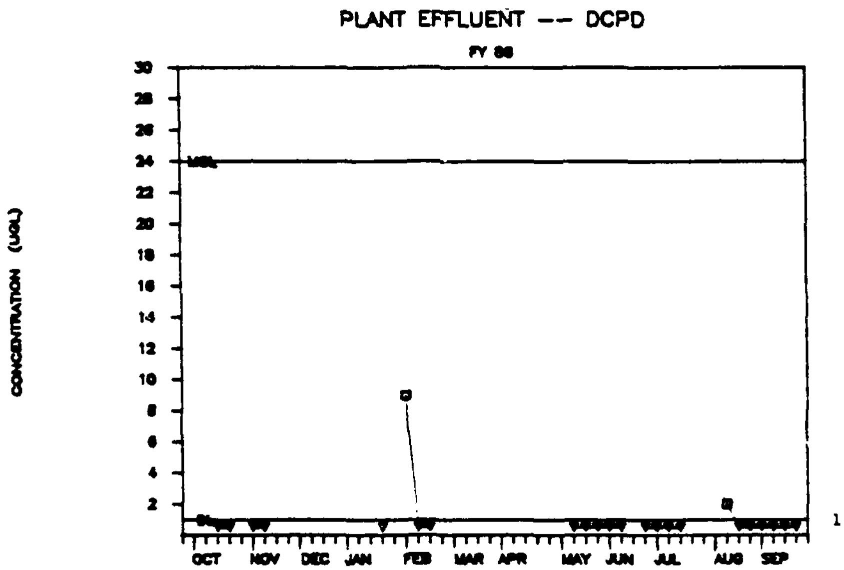


Figure 14. FY86 DCPD (Continued)





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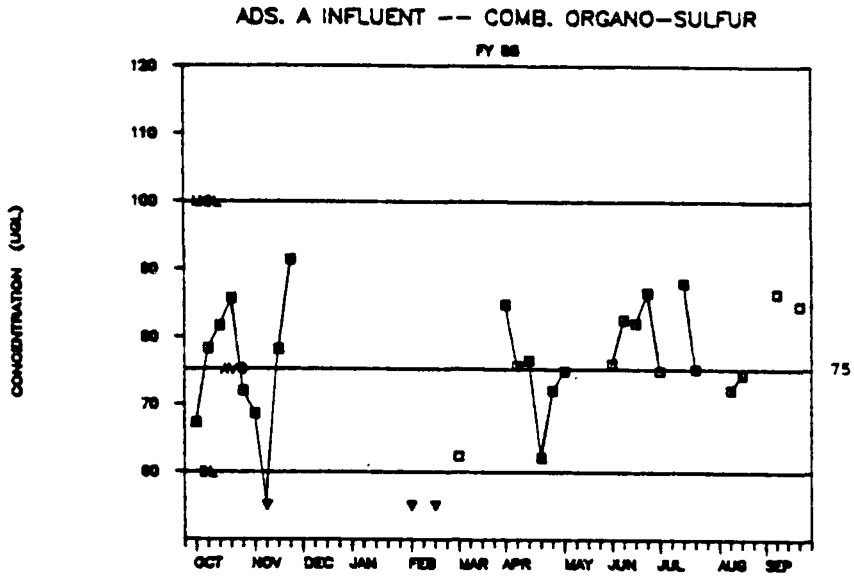


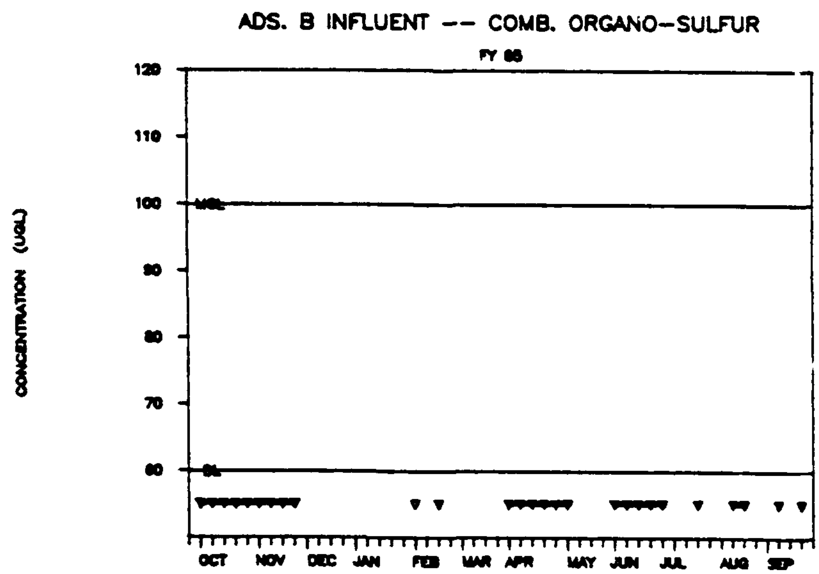
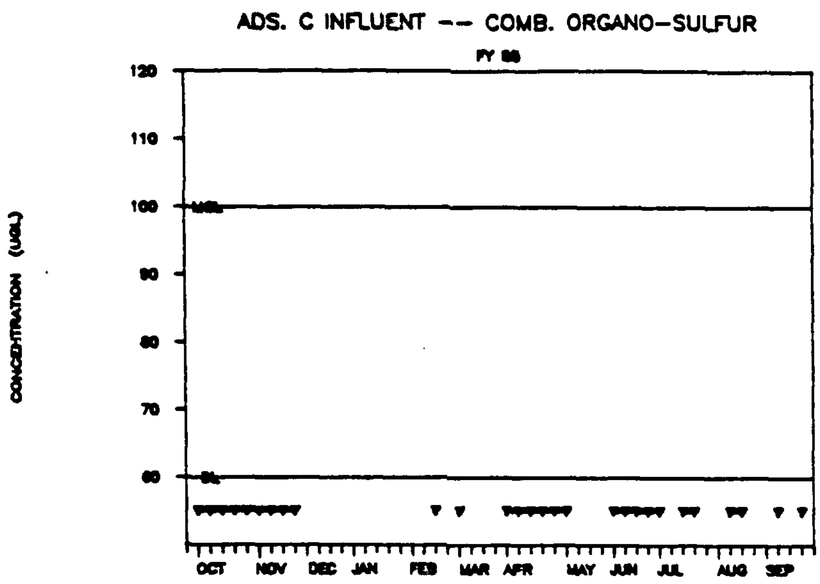
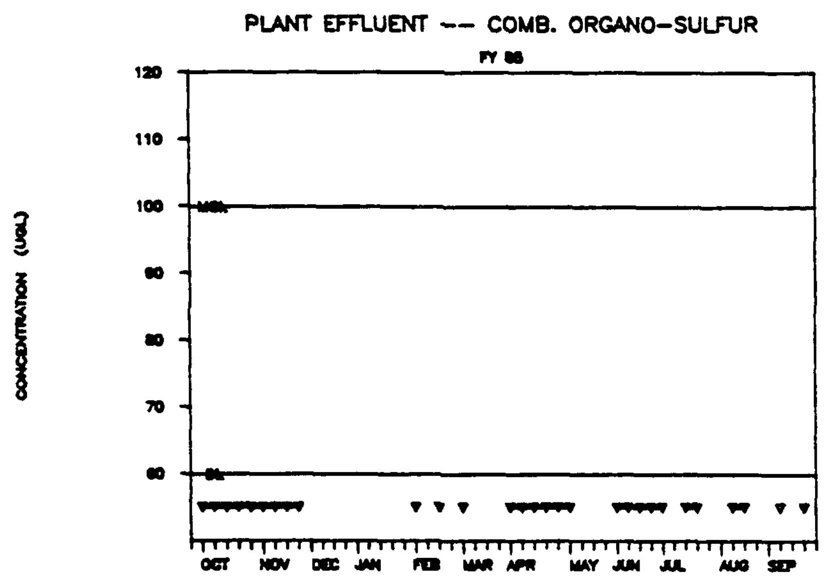


Figure 15. FY85 combined sulfur compounds (Continued)





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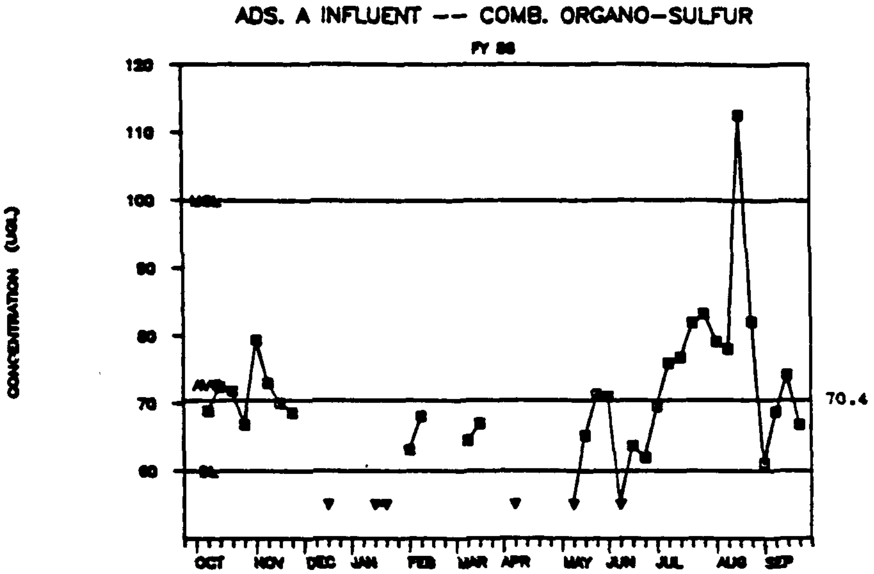


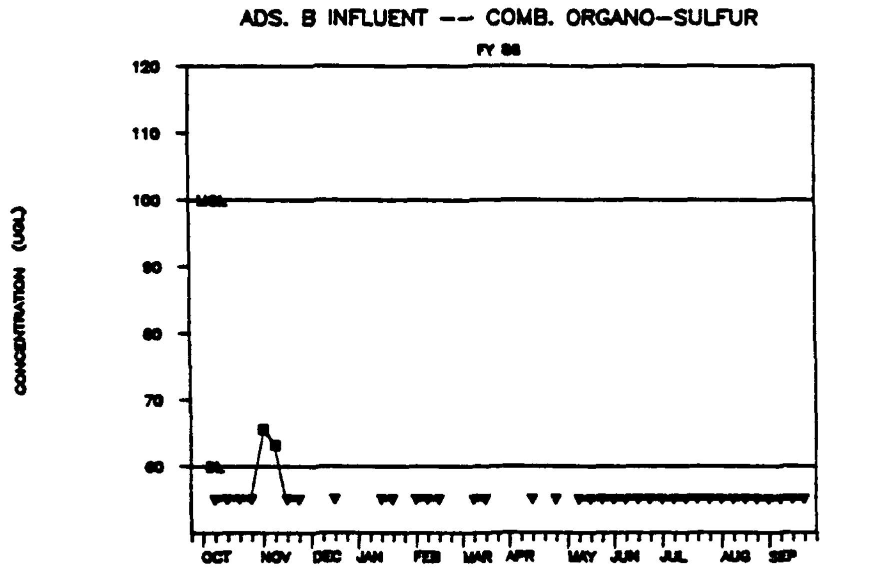
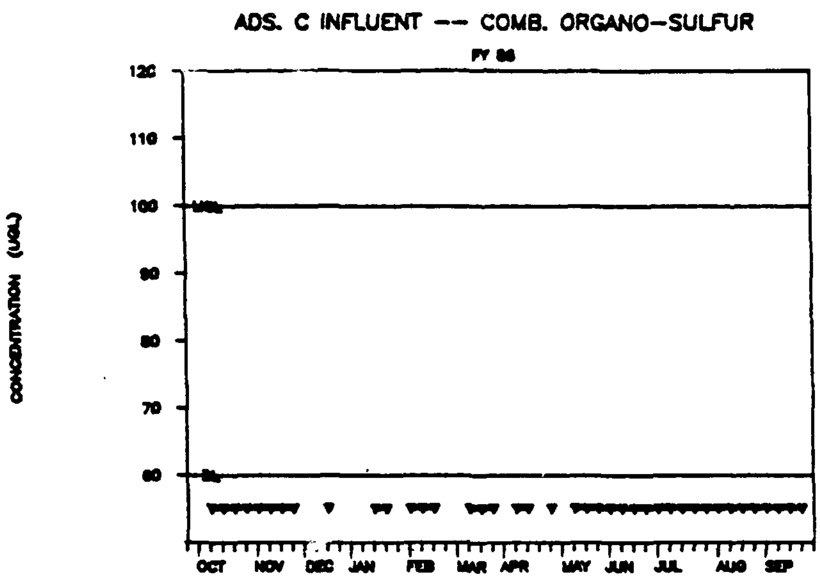
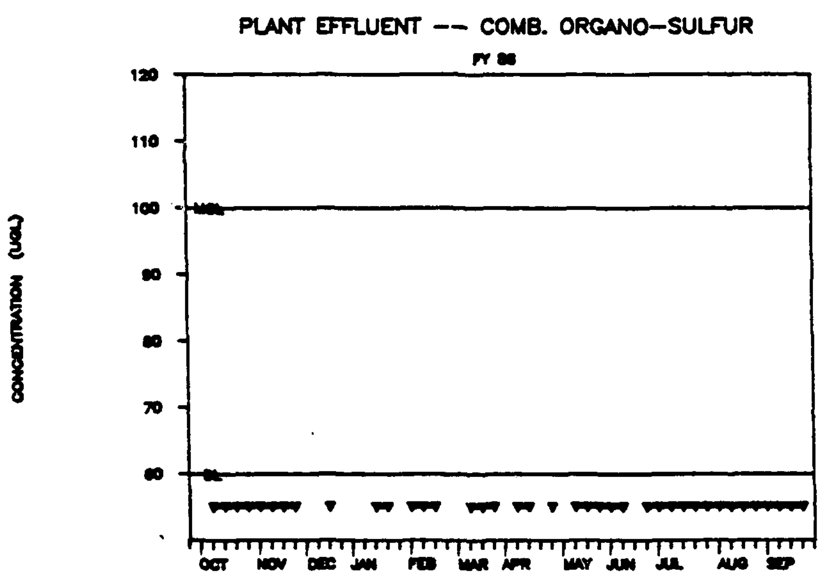


Figure 16. FY86 combined sulfur compounds (Continued)





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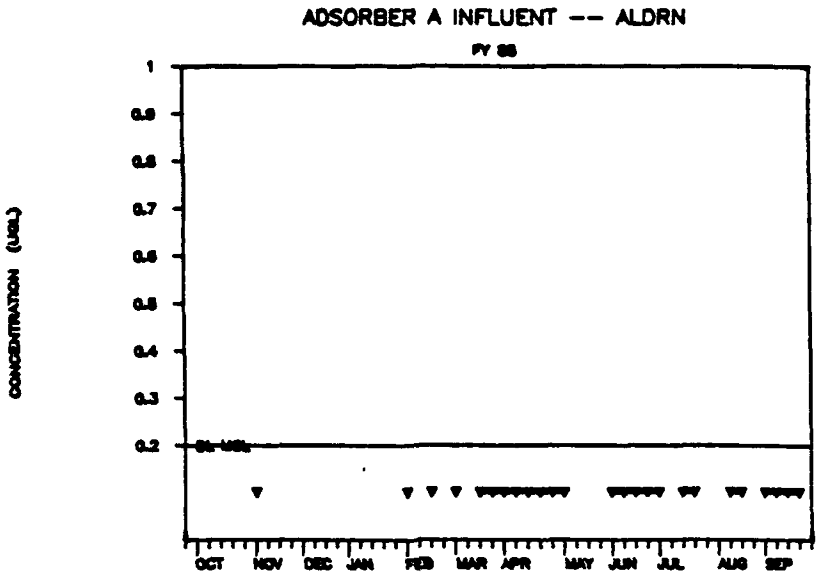


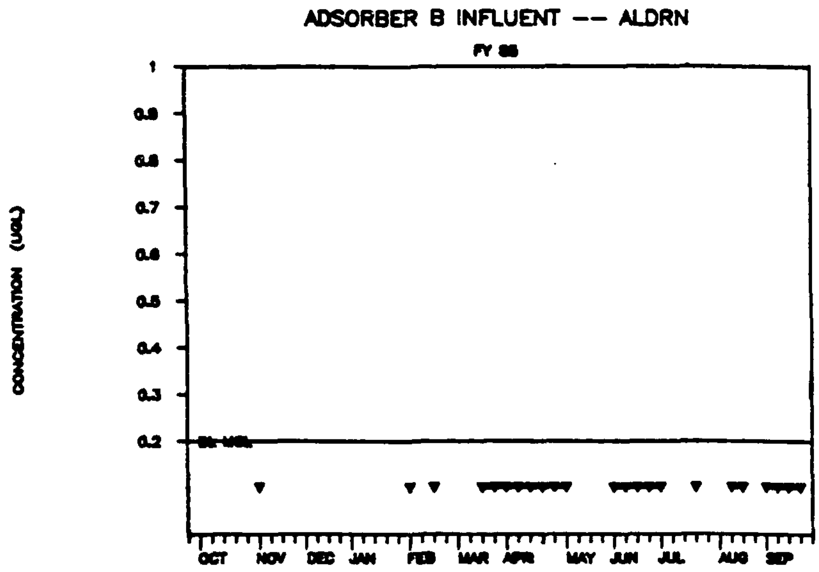
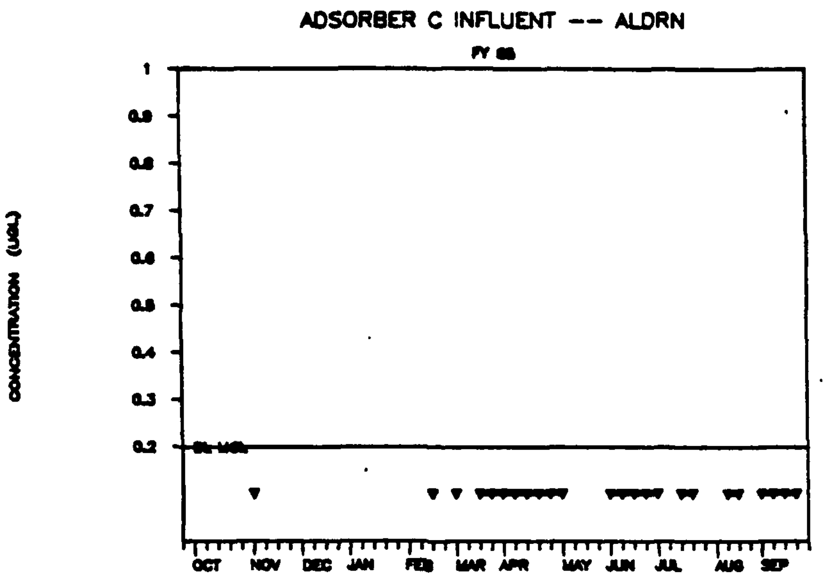
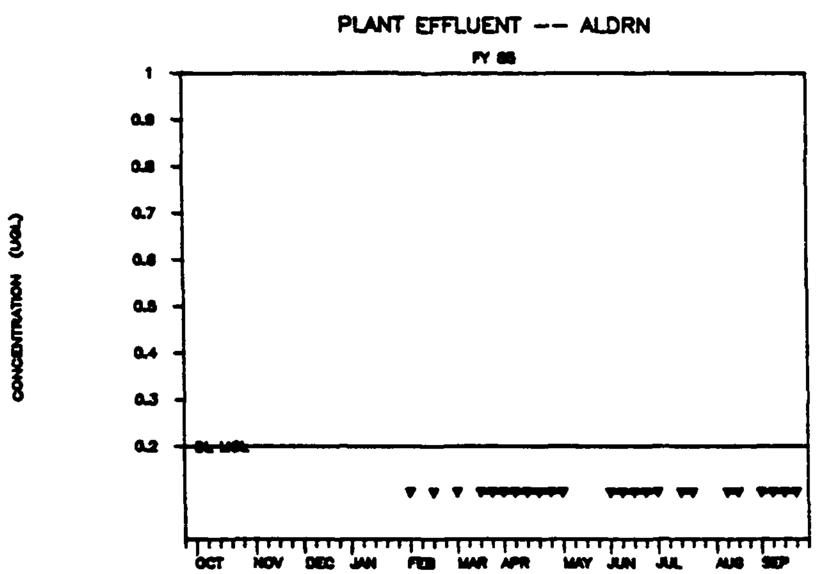


Figure 17. FY85 aldrin (Continued)





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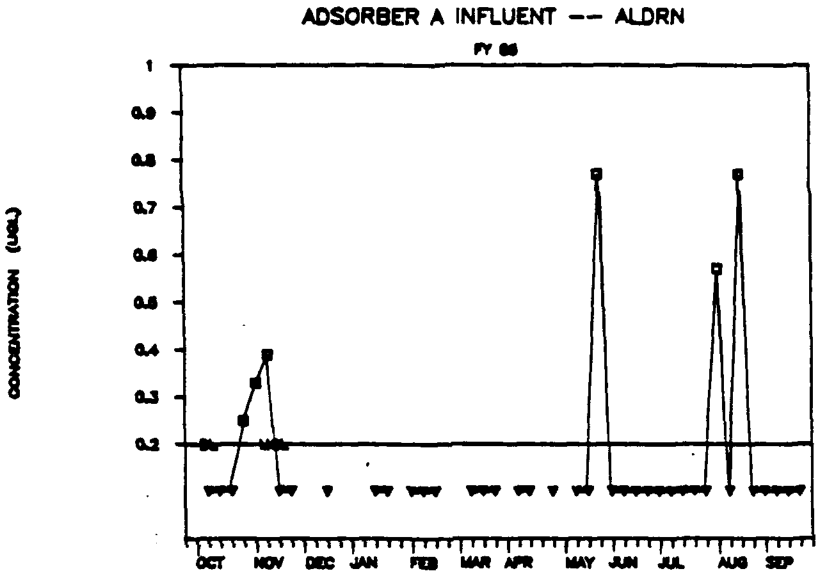


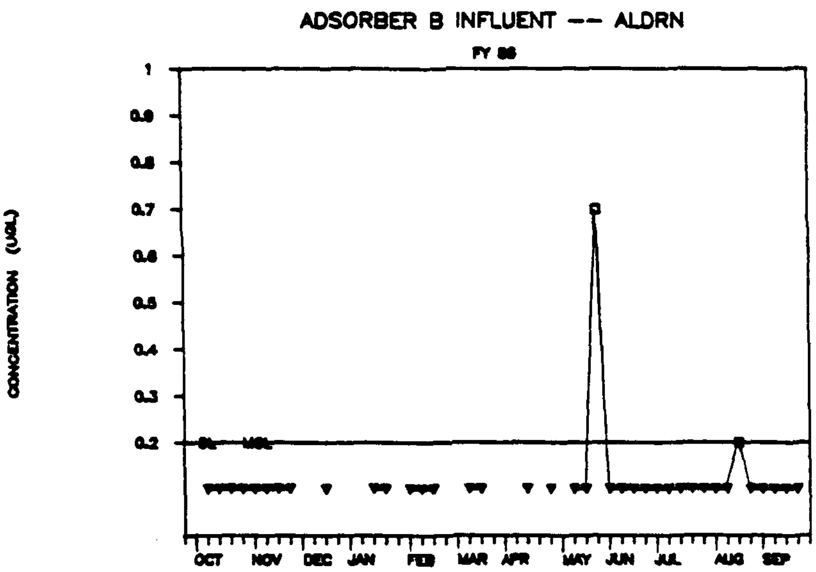
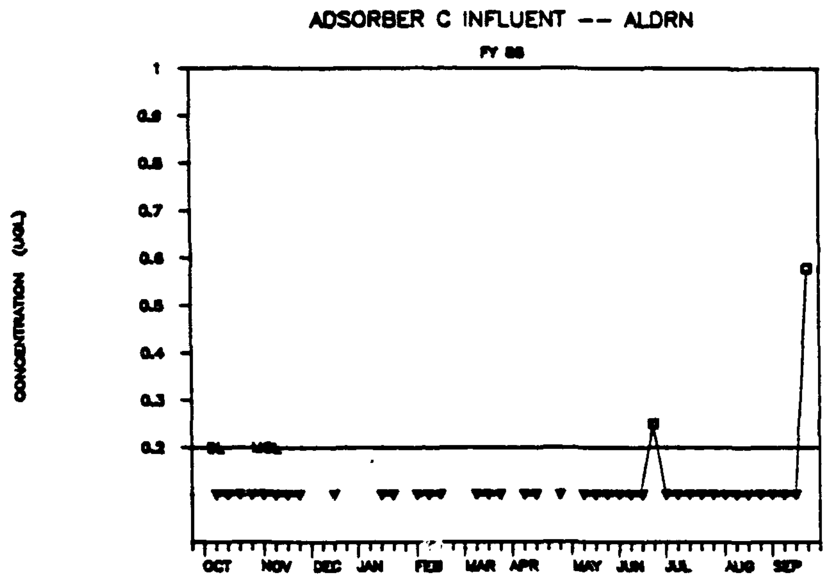
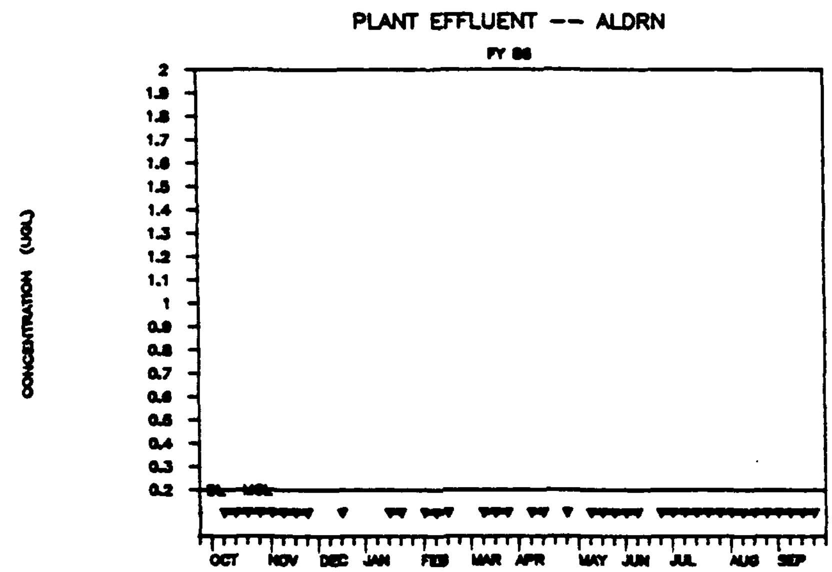


Figure 18. FY86 aldrin (Continued)





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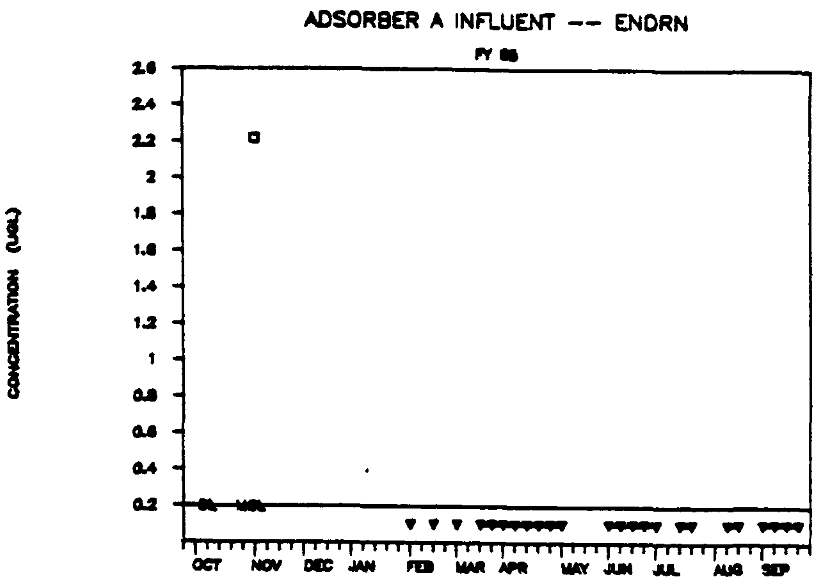


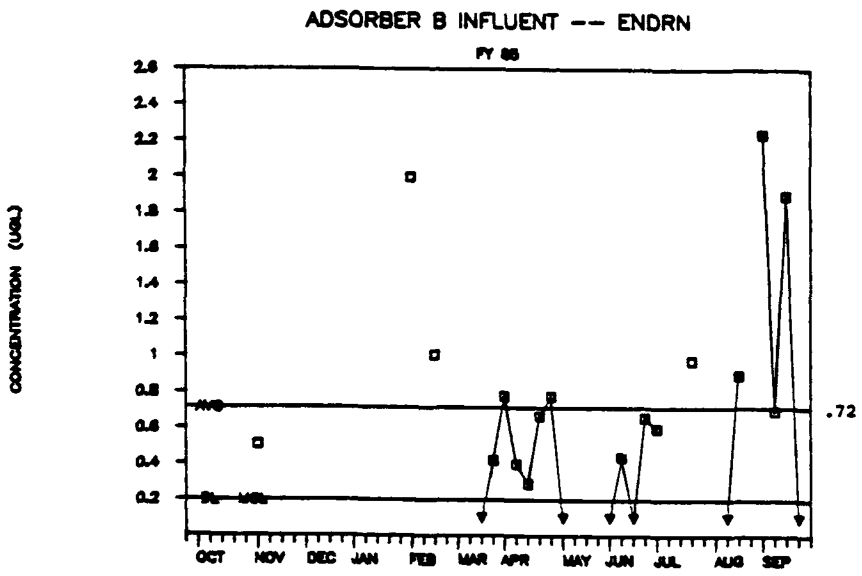
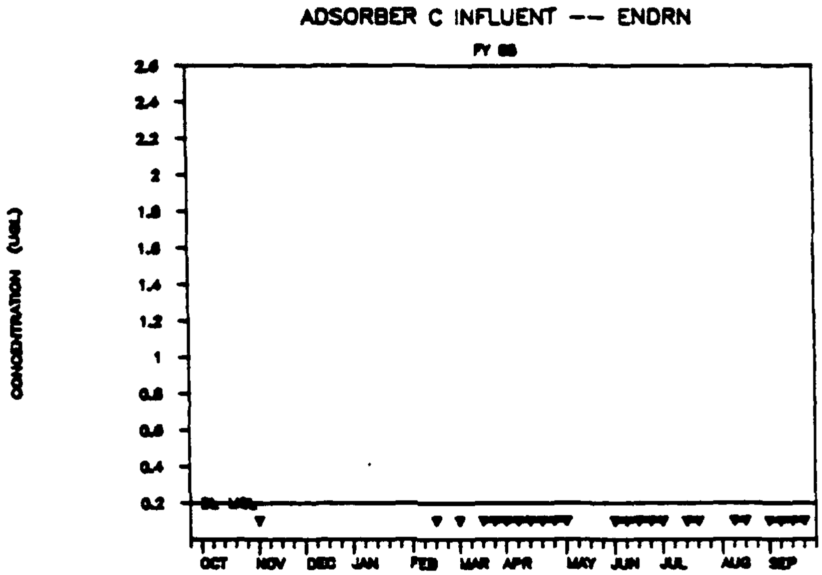
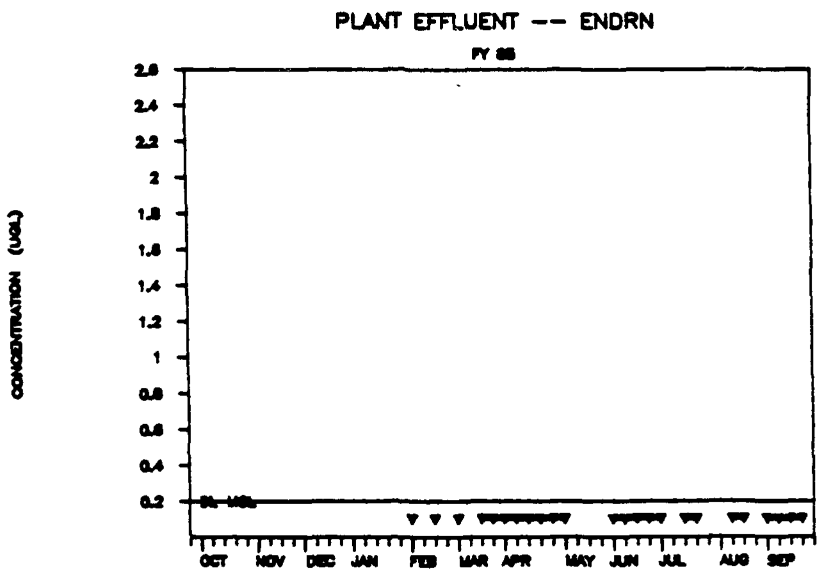


Figure 19. FY85 endrin (Continued)





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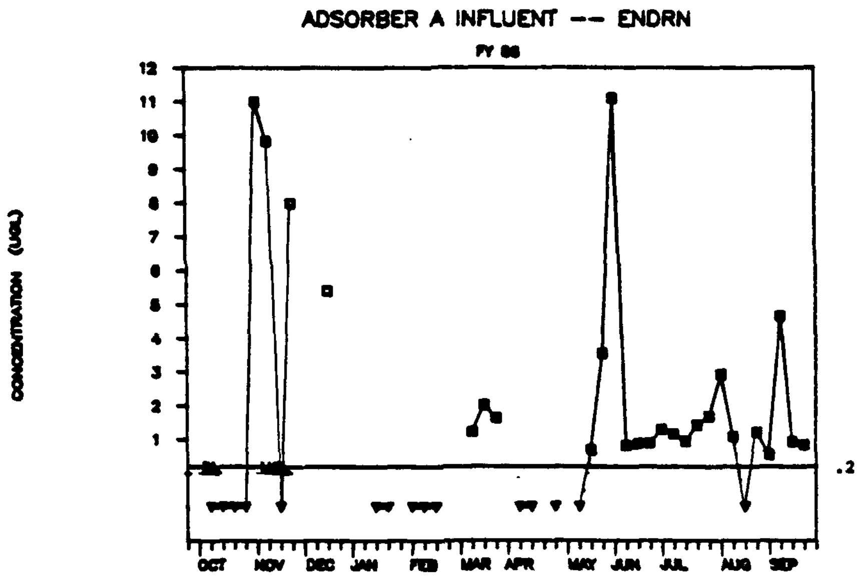


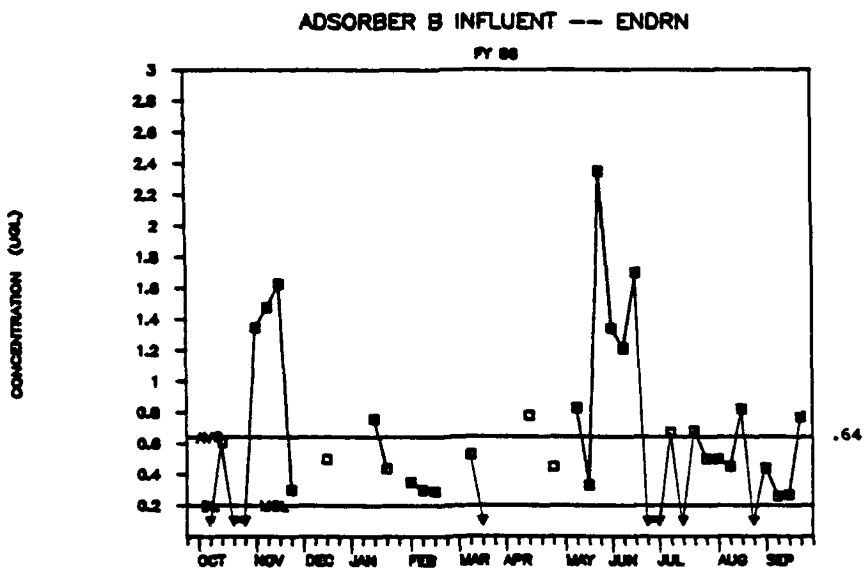
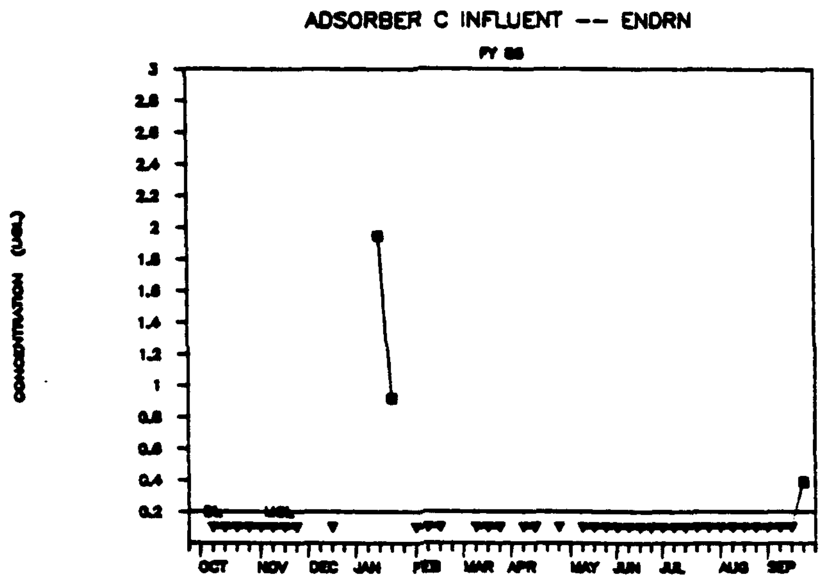
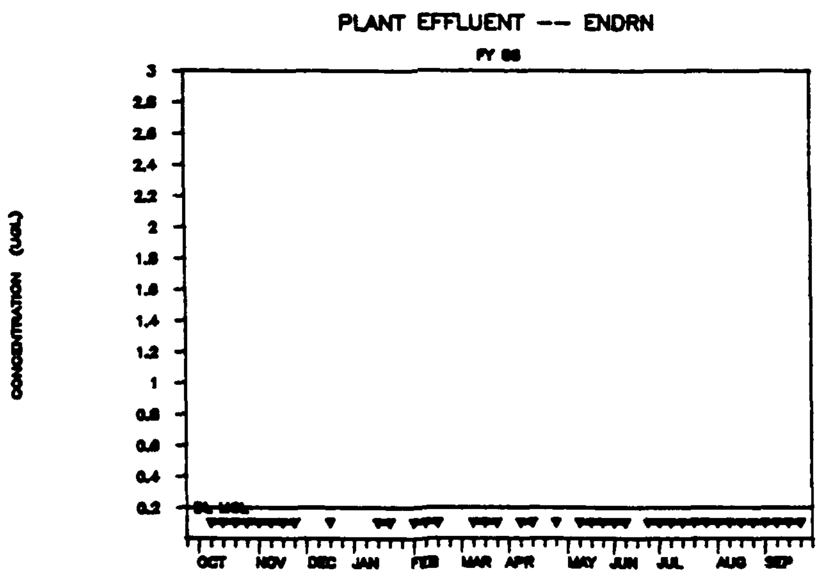


Figure 20. FY86 endrin (Continued)





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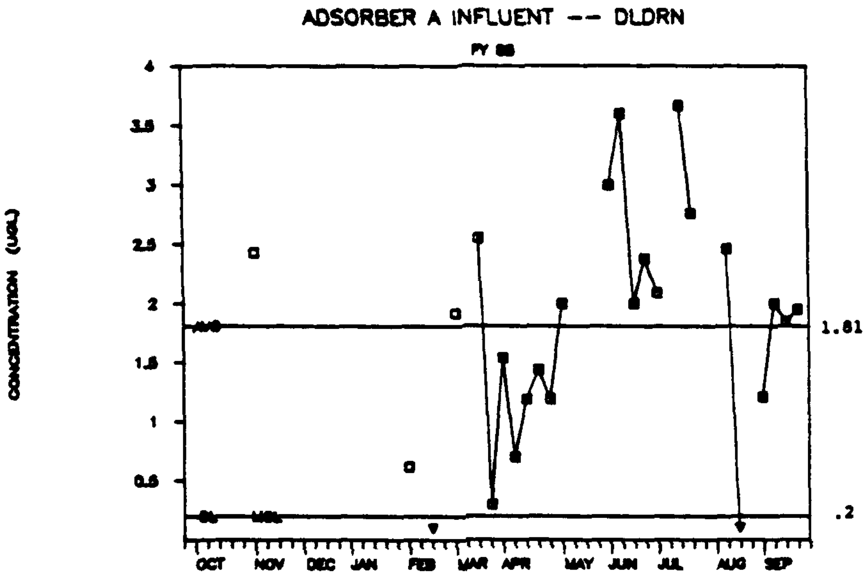


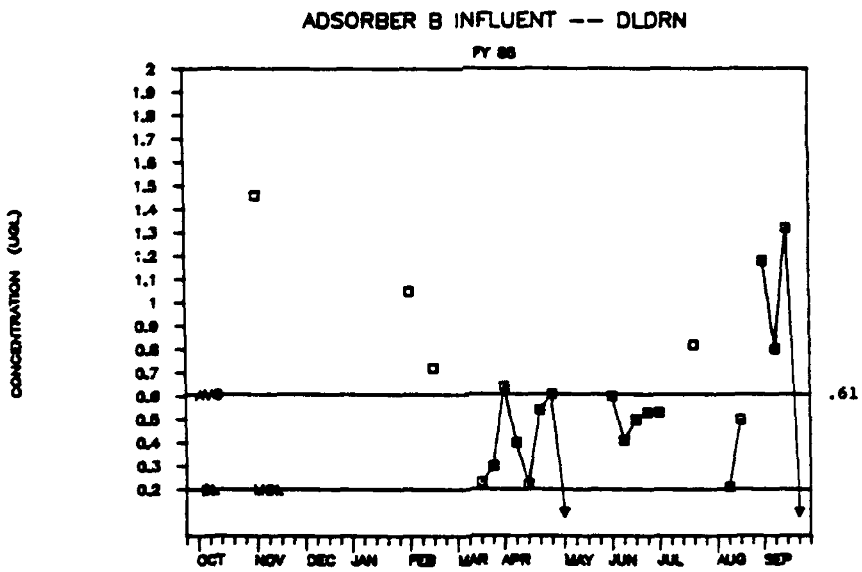
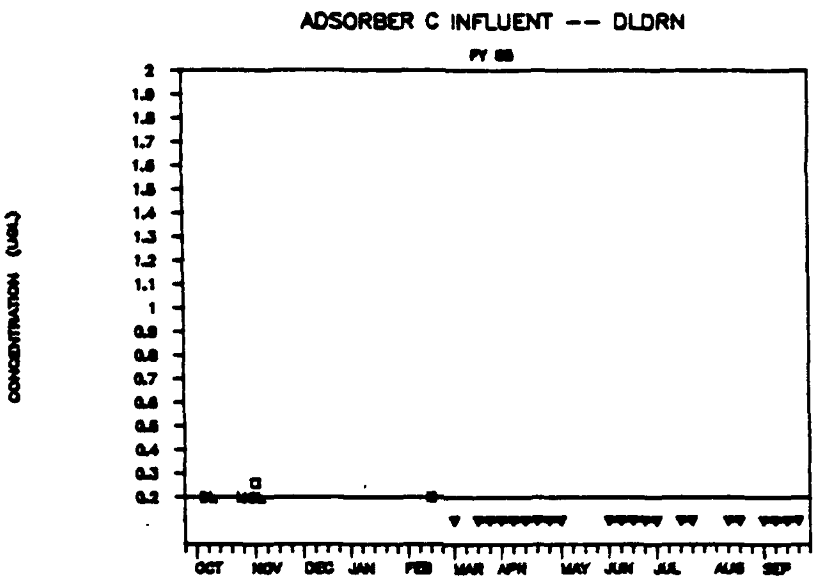
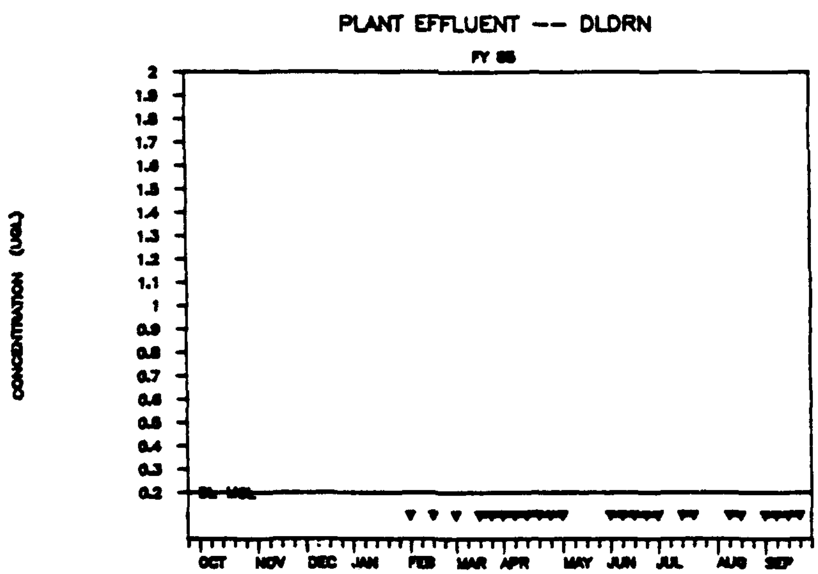


Figure 21. FY85 dieldrin (Continued)





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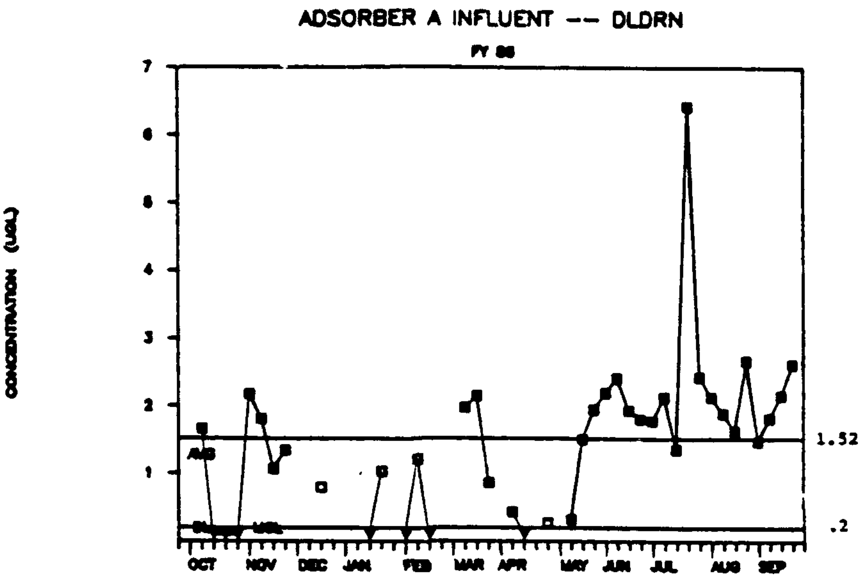


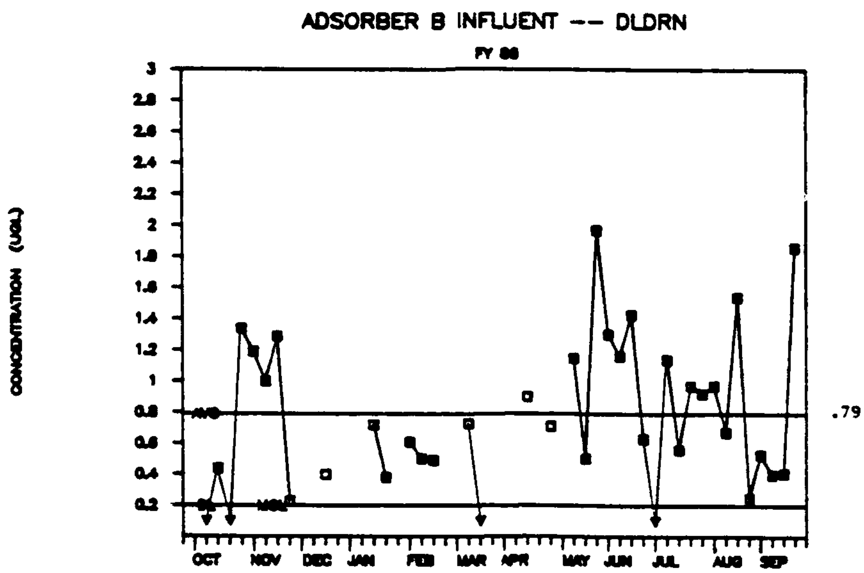
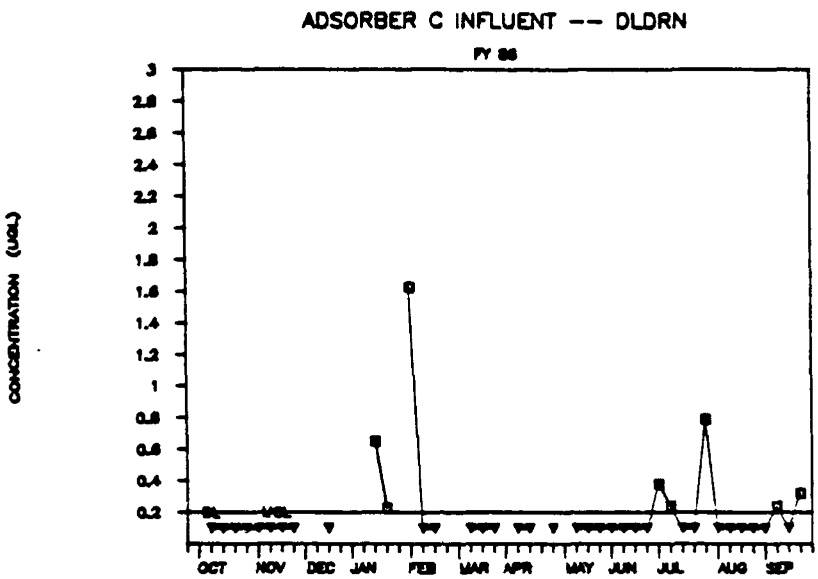
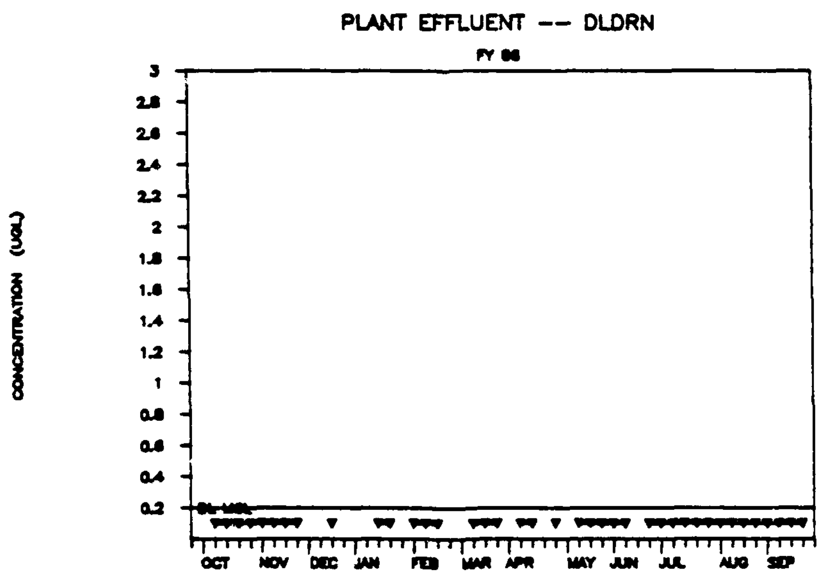


Figure 22. FY86 dieldrin (Continued)





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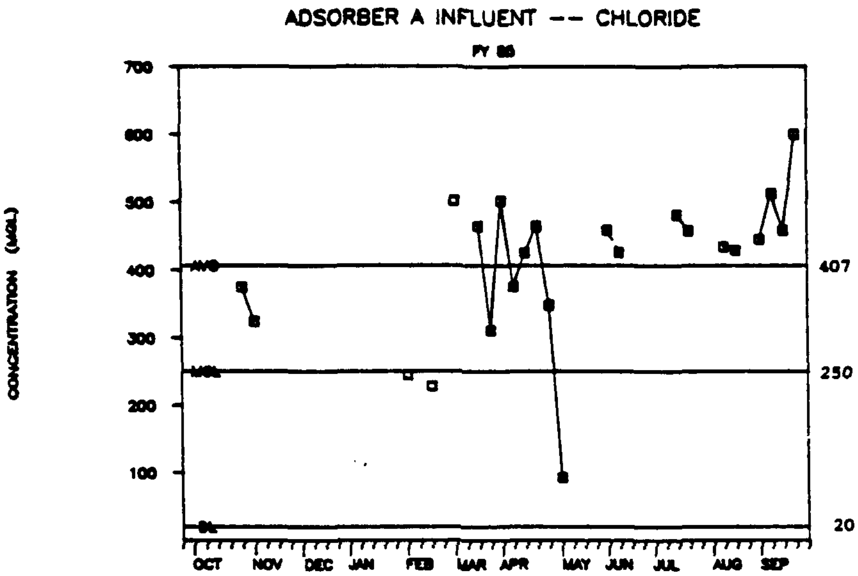


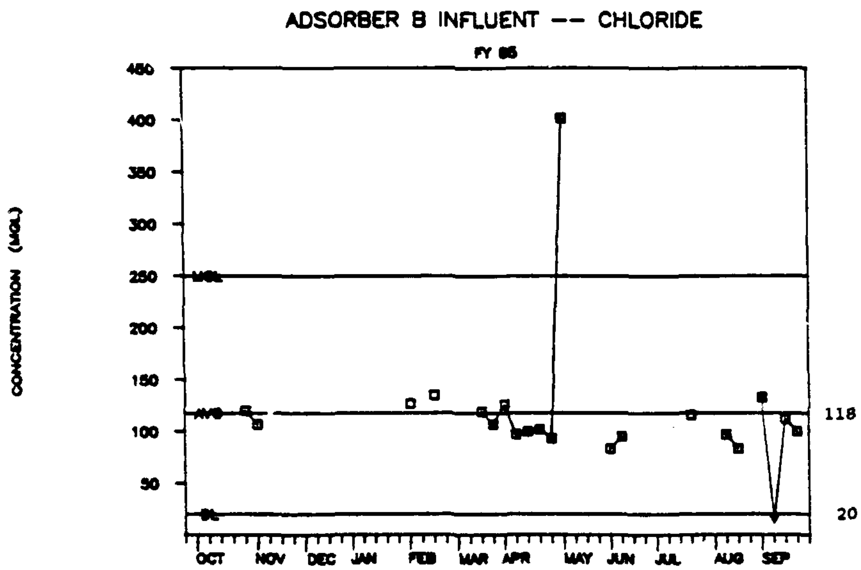
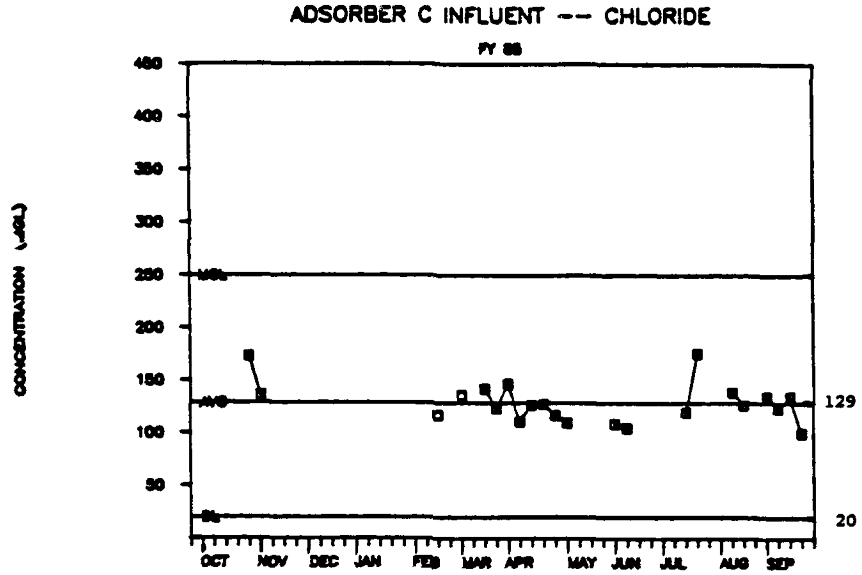
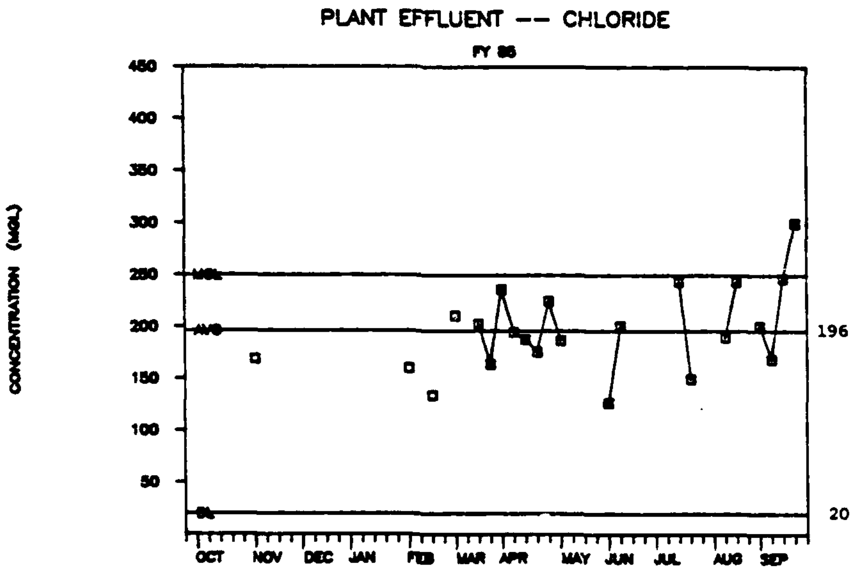


Figure 23. FY85 chloride (Continued)





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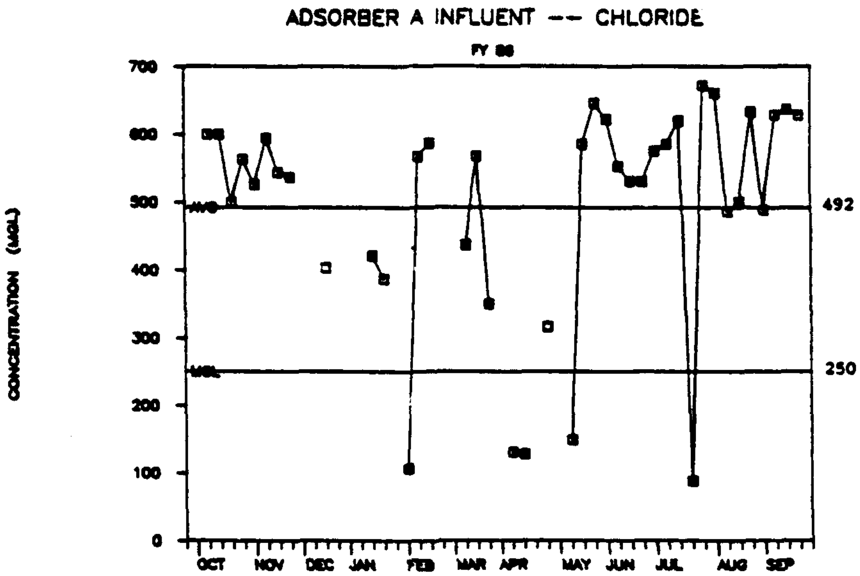


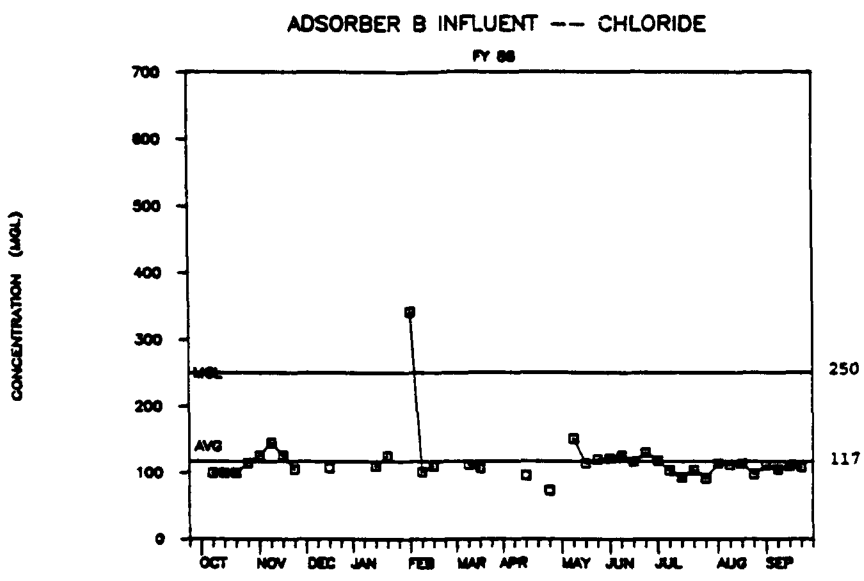
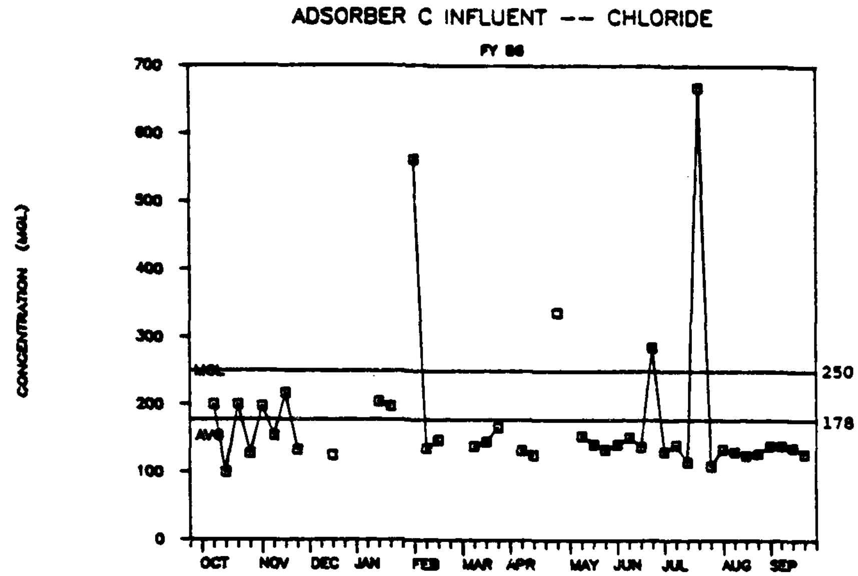


Figure 24. FY86 chloride (Continued)



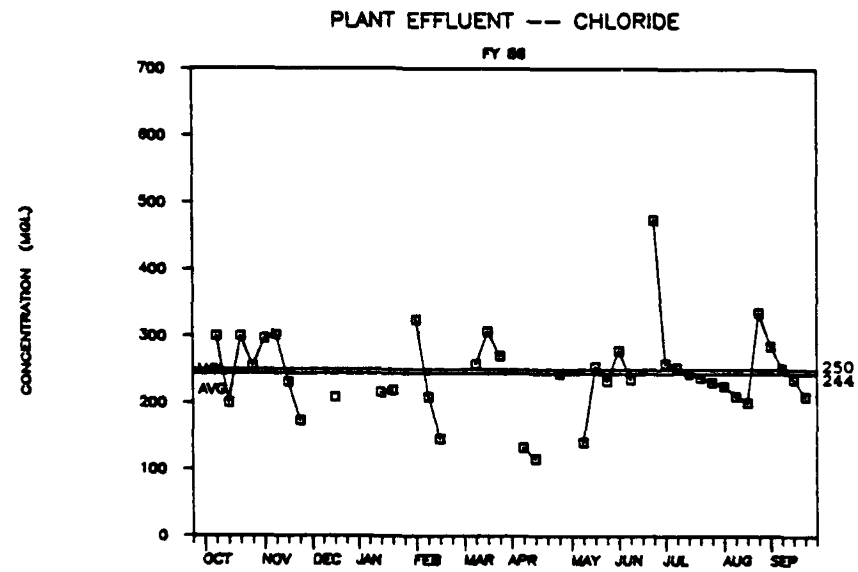
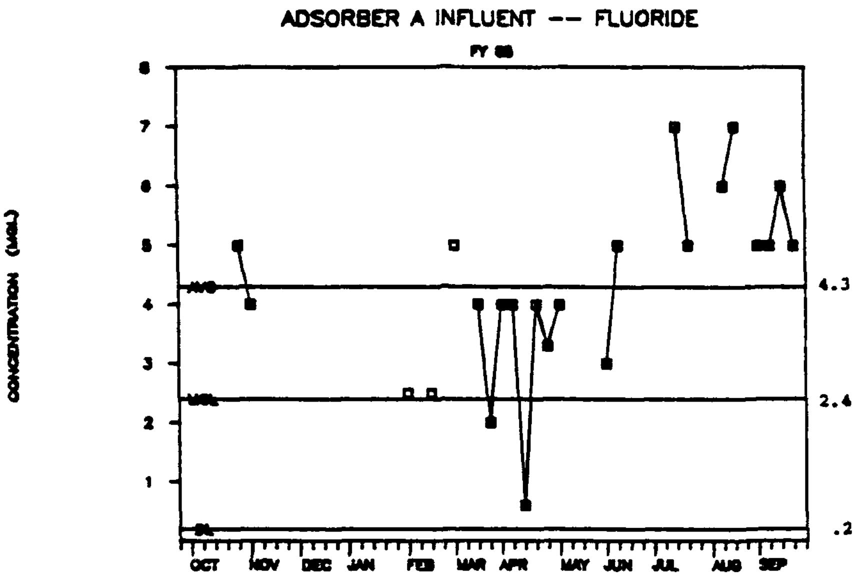


Figure 24. (Concluded)



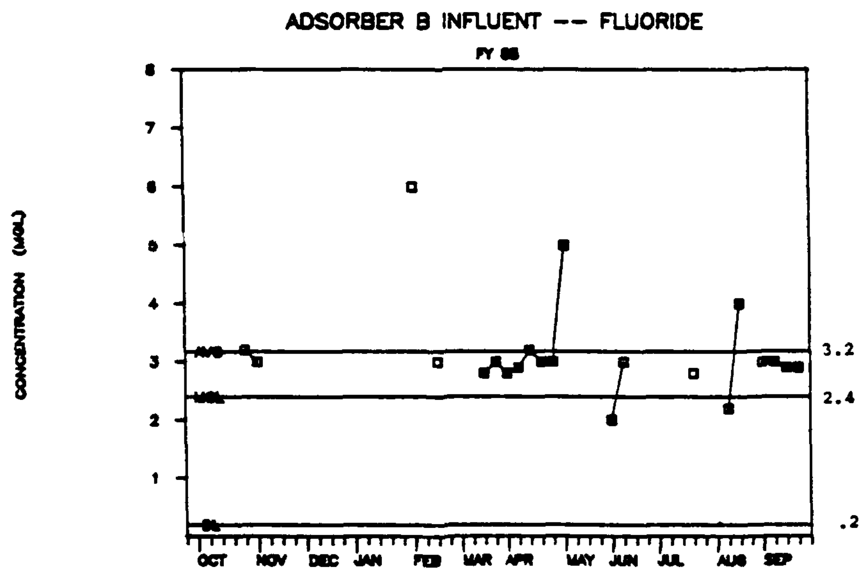
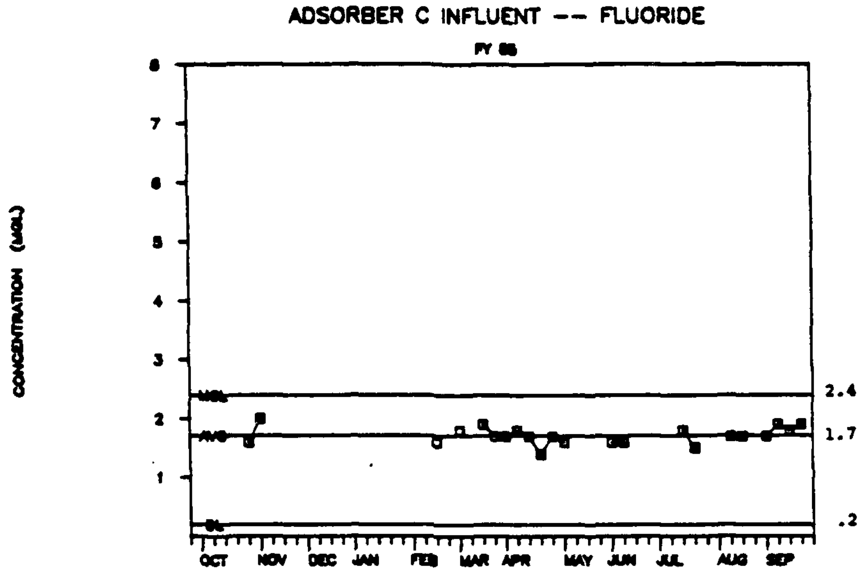


Figure 25. FY85 fluoride (Continued)



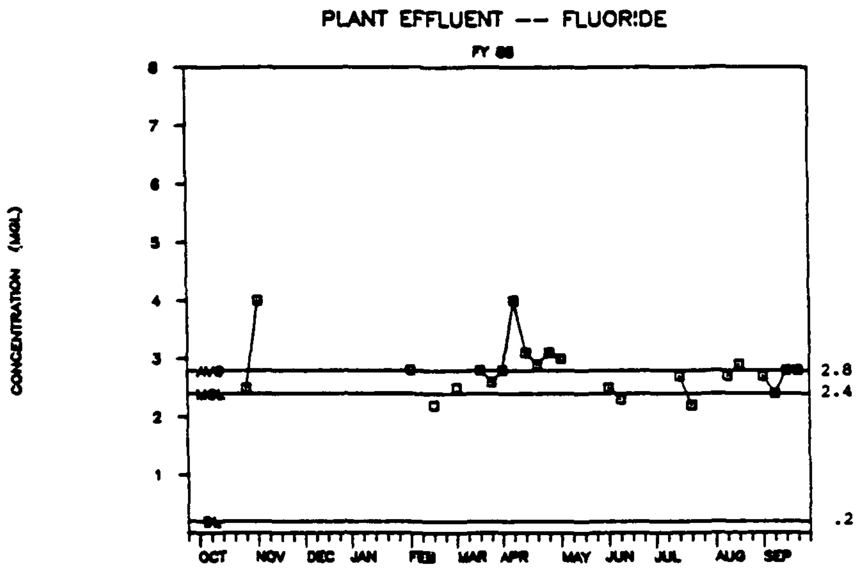
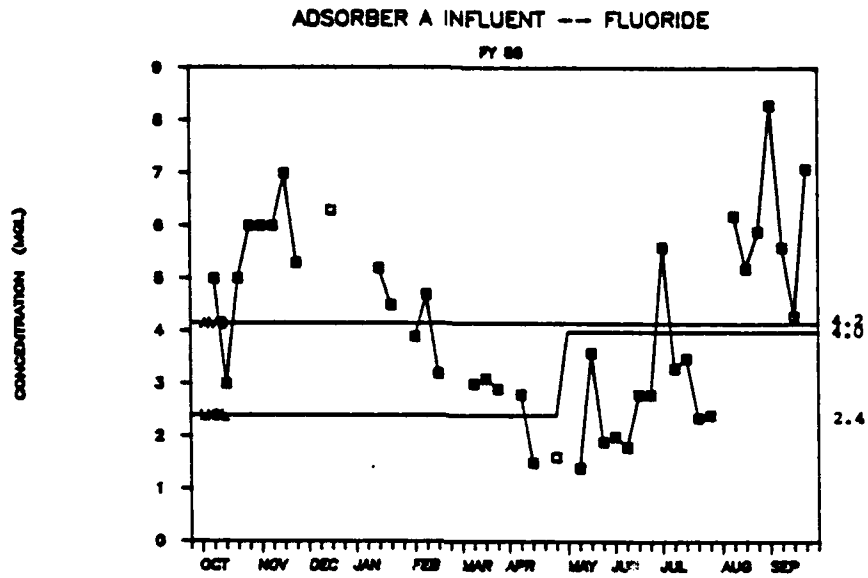


Figure 25. (Concluded)



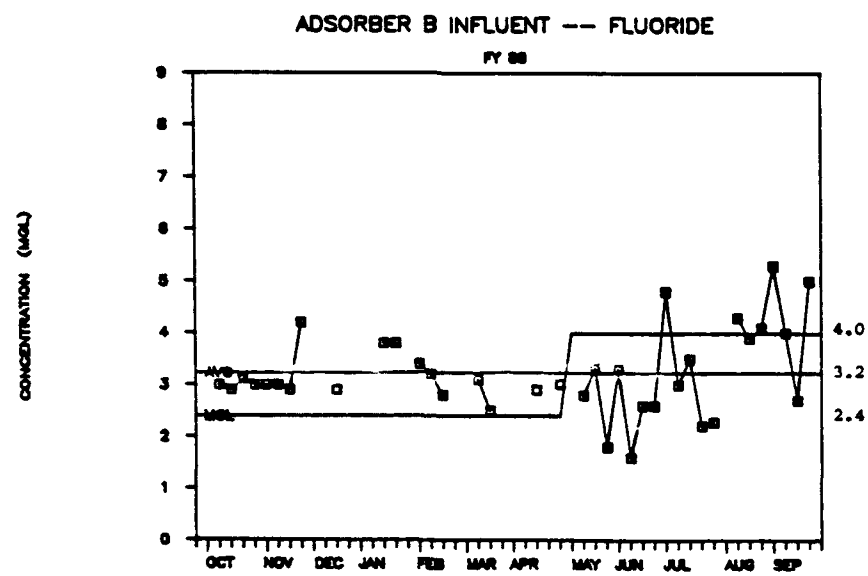
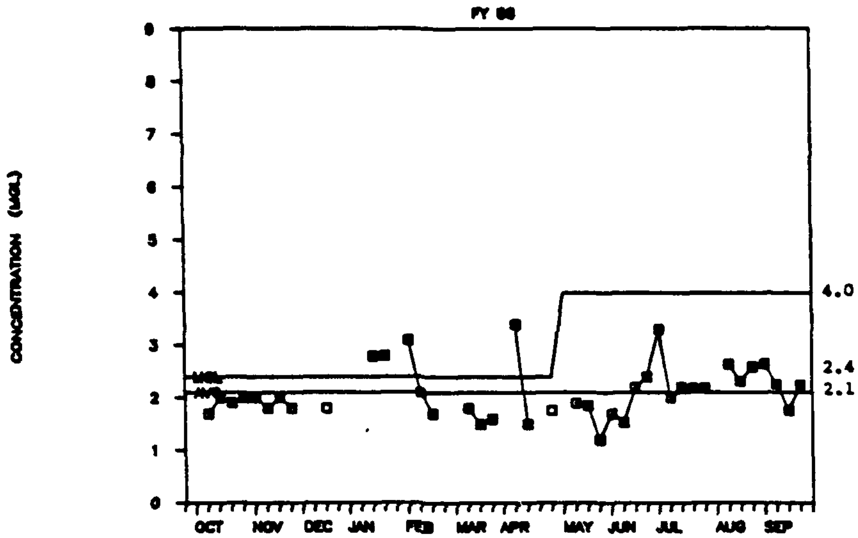


Figure 26. FY86 fluoride (Continued)

ADSORBER C INFLUENT -- FLUORIDE



PLANT EFFLUENT -- FLUORIDE

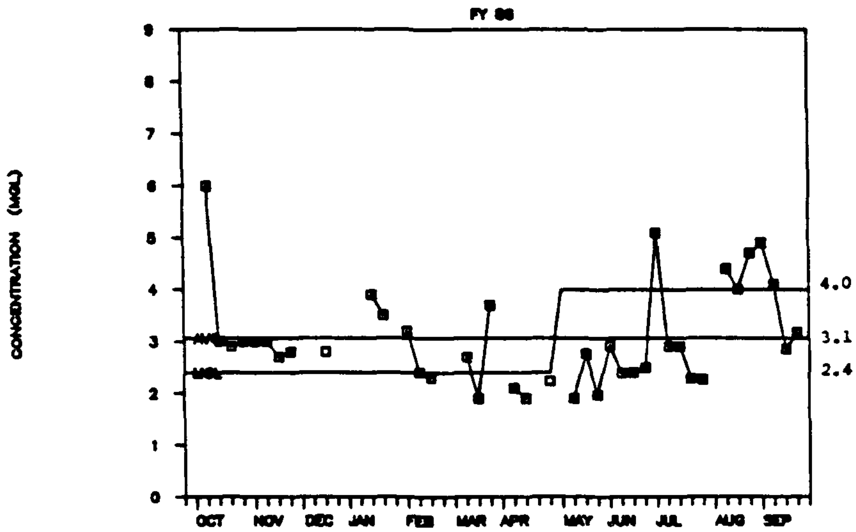


Figure 26. (Concluded)

average. The MOL as used in this report is defined as the water quality criterion against which the operating performance of the treatment plant is compared in order to assess treatment effectiveness for the various contaminants of concern. A list of the MOL's used during the FY85 and FY86 operational assessment is presented in Table 5 pg 57.

28. As discussed by Thompson et al. (1985), each of the three wetwells at the treatment plant (one for each manifold) were to feed an individual adsorber under the original operating scenario. Under this mode of operation, the influent to each adsorber would contain a higher concentration of a particular contaminant than would the others, since the contaminants are not evenly distributed along the length of the barrier. Operational and mechanical problems have resulted in a requirement to periodically distribute water from individual wetwells to more than one adsorber. This action has resulted in fluctuations in the concentrations of contaminants in the influent to each adsorber. Thus, conclusions concerning the increase or decrease in concentrations of contaminants along the three sections of the barrier should not be drawn based on the influent concentration data presented herein.

DBCP

29. The concentration of DBCP in the effluent during FY85 was consistently below the detection level and maximum contaminant level of 0.2 ppb. The highest concentration of DBCP found during FY85 was approximately 3 ppb in the influent to adsorber A. The average concentrations in the influents to adsorbers A and B were just under 1.5 ppb and approximately 0.3 ppb for adsorber C.

30. The concentration of DBCP in the effluent during FY86 was consistently below 0.2 ppb. The highest concentration of DBCP found during FY86 was just under 3 ppb in the influent to adsorber B. The average concentration in the influent to adsorber A was just over 1 ppb and slightly higher in the influent to adsorber B. The average concentration in the influent to adsorber C was 0.36 ppb. The one exception found in September 1986 should probably be considered an anomalous value.

DIMP

31. The highest concentrations of DIMP in FY85 were consistently found in the influent to adsorber A with a maximum concentration of approximately

Table 5

Maximum Operating Limits for North Boundary System

Parameter	Maximum Operating Limit (MOL)	Source*
Aldrin	0.2 µg/ℓ	Guidance from OTSG (Army) until standards are developed (Analytical Detection Limit)
Chloride	250 mg/ℓ	EPA National Primary and Secondary Drinking Water Regulation
Dibromochloropropane (DBCP)	0.2 µg/ℓ	State of Colorado Department of Health limit per letter to Commander, RMA, 26 June 79.
Dicyclopentadiene (DCPD)	24.0 µg/ℓ	These criteria are recommended by the US Medical Bioengineering Research & Development Lab (26 Aug 76) and are based on toxicology studies (26 Aug 76) conducted by the Army. The National Academy of Sciences Committee on Military Environmental Research has reviewed the procedures and results of toxicology studies and concurred in the drinking water levels (1 Feb 77). The State of Colorado has requested the Army to meet a limit of 24 µg/ℓ for DCPD based on an odor threshold value.
Diisoproplymethyl-phosphonate (DIMP)	500 µg/ℓ	
Dieldrin	0.2 µg/ℓ	Guidance from OTSG (Army) until standards are developed (Analytical Detection Limit)
Endrin	0.2 µg/ℓ	EPA National Primary Drinking Water Regulation
Fluoride	4.0 mg/ℓ	EPA Final Rule on Fluoride, National Primary and Secondary Drinking Water Standards, 40 CFR Parts 141, 142 and 143
Combined Organo-Sulfurs	100 µg/ℓ	Guidance from OTSG (Army) until standards are developed

* Source: After Rocky Mountain Arsenal Contamination Control Program Management Team (1983)

650 ppb. The average concentrations found in the influents to adsorbers A and B were 527 ppb and 79 ppb, respectively. Essentially no concentrations of DIMP above the detection level of 10 ppb were found in the influent to adsorber C. The concentration of DIMP in the effluent during FY85 was generally below the detection level of 10 ppb.

32. Like FY85, the highest concentrations of DIMP treated in FY86 were consistently found in the influent to adsorber A. The maximum concentration found was just under 800 ppb. The average concentrations for the year were 565 ppb for adsorber A and 64 ppb for adsorber B. The DIMP concentrations in the influent to adsorber C were generally at or below the detection level. The concentrations of DIMP in the effluent during FY86 were also at or the below detection level.

DCPD

33. The highest concentrations of DCPD in FY85 were consistently found in the influent to adsorber A. The maximum concentration found was just over 1000 ppb. The average concentration found in the influent to adsorber A was 412 ppb. The DCPD concentrations found in the influent to adsorber B were generally less than 25 ppb. Essentially no concentrations of DCPD above the detection level of 1 ppb were found in the influent to adsorber C. No concentrations of DCPD were found in the plant effluent.

34. The highest concentrations of DCPD in FY86 were again found in the influent to adsorber A. The maximum concentration found was approximately 600 ppb with an average for the year of 303 ppb. The concentrations found in the influent to adsorber B were 20 ppb or less with most of the concentrations found to be below 10 ppb. Most of the DCPD concentrations in the influent to adsorber C were at or below the detection level of 1 ppb, however several concentrations values in excess of 100 ppb were noted. Essentially no concentration above the detection level were found in the effluent.

Combined Organo-Sulfurs

35. The highest combined concentration of organo-sulfurs in FY85 was found in the influent to adsorber A at approximately 90 ppb. The average concentration for adsorber A was 75 ppb. No combined concentrations of organo-sulfurs in excess of the detection level of 60 ppb were found in the influent to adsorbers B and C. Also, no concentrations of organo-sulfurs were found in the plant effluent during FY85.

36. The highest combined concentration of organo-sulfurs in FY86, in excess of 110 ppb, was again found in the influent to adsorber A. The average concentration for the year was 70 ppb. During FY86, essentially no combined concentrations of organo-sulfurs above the detection level were found in the influents to adsorbers B and C. No detectable concentrations of organo-sulfurs were found in the plant effluent.

Aldrin

37. No concentration of aldrin above the detection level of 0.2 ppb were found in the influents to the adsorbers. No concentrations of aldrin above detection levels were found in the plant effluent during FY85. During FY86, the most concentration values above the detection level were found in the influent to adsorber A. The aldrin concentrations in the influents to adsorbers A and B were below the detection level of 0.2 ppb. Levels of aldrin in the plant effluent were also below the detection level for FY86.

Endrin

38. The highest concentrations of endrin in FY85 were consistently found in the influent to adsorber B with the maximum concentration found being approximately 2.2 ppb. The average concentration for the year was 0.72 ppb. The endrin concentrations in the influents to adsorbers A and C were essentially all below the detection and maximum operational level of 0.2 ppb during FY85. Likewise, plant effluent concentrations were below the detection and maximum operating levels.

39. The highest concentration of endrin found during FY86 was approximately 11 ppb in the influent to adsorber A. The average concentrations in the influents to adsorbers A and B were 0.2 ppb and 0.64 ppb, respectively. The concentrations of endrin in the influent to adsorber C were generally below the detection level during FY86 with the exception of a couple of values in the adsorber C influent in the range of 1 to 2 ppb. The concentration of endrin in the plant effluent were below the detection and maximum operating level of 0.2 ppb during FY86.

Dieldrin

40. The highest concentration of dieldrin found in FY85 was approximately 3.5 ppb in the influent to adsorber A. The average concentrations for the year were 1.80 ppb for adsorber A influent and 0.61 ppb for adsorber B influent. Dieldrin concentrations found in the influent to adsorber C were

essentially all below the detection level of 0.2 ppb during FY85. The concentration of dieldrin in the plant effluent were below the detection level.

41. The highest concentration of dieldrin found in FY86 was approximately 6.5 ppb in the influent to adsorber A. The average concentrations for the year were 1.5 ppb for adsorber A influent and 0.79 ppb for adsorber B influent. Seven concentration values above the detection level were found in the influent to adsorber C with the maximum being 1.6 ppb. No concentrations of dieldrin above the detection level were found in the plant effluent during FY86.

Chloride

42. The highest concentrations of chloride in FY85 were consistently found in the influent to adsorber A with a maximum concentration of approximately 600 ppm. The average concentration found in the influent to adsorber A was 407 ppm. The influents to adsorbers B and C were found to have average concentrations of 118 ppm and 129 ppm respectively. The average chloride concentration in the plant effluent for FY85 was 196 ppm. There was a considerable amount of variation in the effluent concentrations with a number of values found at, and one value found above, the maximum operating level of 250 ppm.

43. Chloride is not treated by the activated carbon treatment system. Thus, the concentration of chloride in the effluent should approach a flow-weighted average of the concentrations in the influent streams. The variation found in the effluent data reflects the variation in flow quantities through the three manifold subsystems and ultimately the three adsorbers.

44. The maximum chloride concentrations during FY86 were found in the influent to adsorbers A and C at approximately 675 ppm. However, over the year, many more high concentration values were found associated with the influent to adsorber A than adsorber C. This is reflected in the yearly averages. The FY86 averages for adsorbers A, B, and C were 492 ppm, 117 ppm, and 178 ppm, respectively. The yearly average for the plant effluent was 244 ppm, however, there were numerous values over 250 ppm recorded.

Fluoride

45. The highest fluoride concentration in FY85 of approximately 7 ppm was found in the influent to adsorber A. The average influent concentration for the year to adsorber A was 4.3 ppm, however, the values observed varied widely. The fluoride concentrations found in the adsorber A influent showed

an increasing trend from the March/April timeframe to the August/September timeframe. This trend is much more pronounced than for any of the other contaminants investigated. The FY85 average concentrations for influents to adsorbers B and C were 3.2 ppm and 1.7 ppm, respectively. The average fluoride concentration in the plant effluent was 2.8 ppm which is higher than the maximum concentration level of 2.4 ppm. Like chloride, fluoride is not treated by the treatment system.

46. During FY86, a maximum fluoride concentration of approximately 8 ppm was found in the influent to adsorber A. The average concentration for the year was 4.2 ppm, but, the concentrations found varied widely. The fluoride concentrations peaked in November 1985 at approximately 7 ppm, decreased to the 2 to 3 ppm range during May and June, 1986, and then increased to a maximum value in September 1986. The FY86 average fluoride concentrations in the influents to adsorbers B and C were 3.2 ppm and 2.1 ppm, respectively. The average fluoride operating in the plant effluent was 3.1 ppm. Also, the maximum operating level for fluoride increased from 2.4 ppm to 4.0 ppm in April 1986, as a result of EPA's final rule on fluoride, National Primary and Secondary Drinking Water Standards (40 CFR Parts 141, 142 and 143) published April 2, 1986 in the Federal Register.

47. Also, review of plant effluent fluoride data during FY86 has indicated analytical values above 4.0 ppm on sample Julian date 183 and for samples taken between Julian date 225 through 253. A thorough review of relevant factors (i.e. treatment plant procedures, process conditions, sampling and analytical procedures, water quality data etc.) was made by PM, RMA to determine the possible cause for the elevated levels. Results of the investigation indicated that laboratory analytical work apparently caused fluoride values to be reported higher than actual concentrations during the timeframe in question. RMA has taken steps to enhance laboratory accuracy for fluoride analysis.

Carbon Usage

48. A summary of the data on carbon usage in the treatment plant for FY85 and FY86 is presented in Table 6. Approximately 87,000 and 114,000 lbs of activated carbon were used during FY85 and FY86, respectively. The highest usage rates were observed for adsorber A, approximately 1.5 lbs per

1,000 gallons of water treated for both FY85 and FY86. The usage rates for adsorbers B and C were much lower than for adsorber A, and were considerably higher in FY86 than in FY85.

Table 6

Carbon Usage in the Treatment Plant

	Total Carbon Used		Usage Rate	
Adsorber	FY85 (lbs)	FY86 (lbs)	FY85 (lbs/1,000 gal)	FY86 (lbs/1,000 gal)
A	52,972	56,557	1.47	1.54
B	26,546	38,345	0.58	0.88
C	7,361	19,070	0.19	0.41
TOTAL	86,879	113,972		

PART IV: DATA EVALUATIONS

GEOLOGY AND HYDROGEOLOGY

General Setting

49. The geology and hydrogeology of the North Boundary were described previously by Thompson et al. (1985). The two geologic units of concern along the North Boundary are the recent alluvium and the underlying Denver formation. The alluvium is composed of silts, clays, sands and gravels. The sands and gravels most commonly occur in the lower alluvium and the finer soils in the upper alluvium. The alluvium is approximately 20 to 30 ft thick in the vicinity of the containment system. The alluvium has an approximate 10 to 20 ft saturated thickness at the North Boundary at a depth of 5 to 15 ft below ground surface. Saturated thicknesses as great as 25 ft occur in the valley fill upgradient of the boundary. The Denver formation which underlies the alluvium is composed mainly of clay shale and claystone interbedded with some fine to medium grained sand units. Within the Denver formation there are local saturated sand units with artesian conditions.

50. Hydrogeology. In the vicinity of the containment system, the ground-water flow is northward between two Denver formation highs. The ground-water flux in the alluvial aquifer at the North Boundary was estimated during the original design phase (Black and Veatch, 1980) at 640,000 gallons per day (444 gpm). Flow measurements and water level data indicate that the flows were in the range of 250 to 325 gpm (Thompson et al. 1985). Normally, the permeability in the coarse grained alluvium is three orders of magnitude larger than in the Denver sands.

51. The flow of alluvial ground water is influenced by the paleodrainage surface on the underlying Denver formation. A contour map of the Denver surface was presented in Thompson et al. (1985) and is reproduced as Figure 27. A significant paleodrainage feature defined by contours on the map is an apparent broad, buried stream valley that enters the North Boundary area from the southwest corner and crosses the barrier about 500 feet east of the "D" Street intersection. The slurry wall was constructed across the buried valley. The valley has a maximum width of 4000 ft in Section 23 (Figure 27) and is defined by paralleling Denver highs on each side. A large portion of the valley surface is relatively flat and slopes in elevation from about

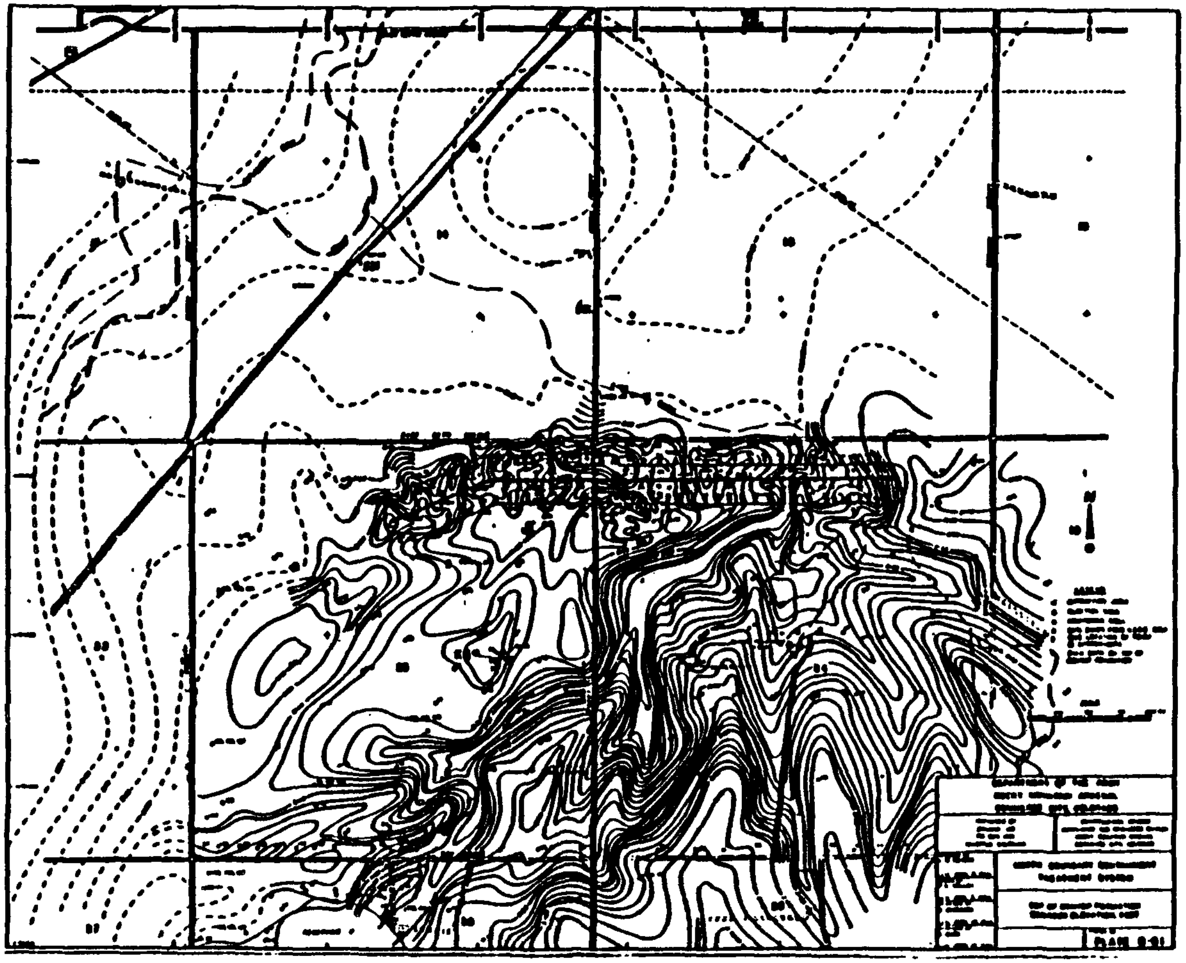


Figure 27. Contours on top of Denver Formation, North Boundary, Rocky Mountain Arsenal (Thompson et al. 1985).

5148 ft MSL at the northern end of Basin F to 5130 feet MSL near the north boundary. A deeper channel, incised approximately 15 feet lower in the Denver than the average valley floor, extends from beneath the northwest end of Basin F to the eastern end of the barrier wall. The deeper channel is narrow near Basin F, gradually widens toward the north, and intercepts paleodrainage from the North Plants and First Creek areas at points near the east end of the barrier wall.

52. In effect all alluvial ground water, from Basin F to east of First Creek, is funneled across the north boundary of RMA through the old stream valley where the barrier was constructed. Although alluviation and subsequent erosional processes have largely obscured the present surface expression of the buried river valley, the surface drainage is similar in flow direction to underlying paleodrainage. The direction of flow of the alluvial ground water, defined by the ground-water contours in Volume II Plates 1 through 8, generally parallels the buried stream valley between the Denver formation highs. Water collecting in the alluvium overlying the highs drains at locally high gradients down into the thick alluvium of the buried valley (see Plates 1 through 8). The water table is relatively flat within and across the valley and alluvial ground water flows at relatively low gradients toward the barrier.

53. Alluvial deposits filling the buried valley consist largely of silts, sands and gravels. Ground water flows readily through the coarse grained alluvium and provides the primary transport for ground water contaminants from the direction of Basin F toward the north boundary of RMA. Most of the contaminant plumes are associated with this ground water flow.

54. Subsurface geology defined by borings. Eleven geologic cross sections were constructed in the area of the North Boundary containment system. Cross sections and their locations were presented in Thompson et al. (1985), Volume II, Plate G-2. The alluvium shown on all the cross sections (Thompson et al. 1985) generally represents an upward fining sequence of basal gravelly sands and upper silts and clays. The general stratigraphic sequence was disturbed by secondary cut and fill processes of local streams migrating back and forth across the alluvial deposits. As a result of the cut and fill processes, many of the alluvial lithologic boundaries along the cross sections conform to the geometry of former stream channels. In several areas, the channels have cut entirely through the basal gravels and have back-filled with

clays, clayey sands, and silts on top of the underlying Denver formation. Lateral changes, for example from gravelly sand to clayey sand or from sand to clay, are common occurrences and have no predictable sequence.

55. Analysis of the borings and cross sections along the North Boundary System was made in Thompson et al. 1985. Pertinent conclusions drawn from the analysis were: (a) Screens for some of the dewatering wells upgradient of the barrier are in gravelly sands cemented with secondary calcium carbonate. Output from these wells may be hampered by the cementation. (b) Denver formation sand and silt lenses and channels lie above and below the base of the barrier wall in some areas, particularly in the area of the pilot site. (c) Many of the recharge wells west of the pilot site were screened in alluvial clay. Most of the recharge wells east of the pilot site were screened in sands and gravels. Problems with recharging treated ground water to the aquifer would be expected west of the pilot site.

Ground-Water Hydrology

56. Background. Thompson et al. (1985) presented a brief hydrologic history of the north boundary area and identified factors that have influenced the operation of the barrier system and the ground-water conditions. Factors included operation of the sewage treatment facility in Section 24, numerous pump tests, pumping and irrigating in Sections 23 and 24, operation and testing of the Pilot Containment System, and construction and operation of the North Boundary System. The water table gradient across the barrier was reported to be steep and was attributed to difficulties in dewatering south of the barrier and in recharging to the aquifer north of the barrier.

57. Water levels. Water table elevation maps were constructed for this report for each quarter of FY85 and FY86. The maps are presented as Plates 1 through 8 and are for November 1984, January-February 1985, April-May 1985, July 1985, October 1985, March 1986, May-June 1986, and August 1986. Maps for time periods before November 1984 were presented in Thompson et al. 1985. Water levels are contoured on 1-ft intervals with auxiliary half-foot intervals in the thick alluvial valley where the gradient is low. Areas that do not contain water bearing alluvium, as defined by well data, are separated from water-bearing areas by bold dashed lines on the contour maps.

58. The water level elevation maps indicate that the water level fluctuation is seasonal: high levels in the winter and spring, low levels in the summer and fall. To assist in analysis of water level data concerning

quarterly changes in the water table levels and gradients, water level profiles were constructed through selected wells. Plate 9 shows the location of the profiles.

59. Analysis of water level changes from profiles. Figures 28 and 29 are profiles of water levels for each quarter of FY 85 along lines of "indicator" wells (wells chosen for comparison of quarterly water levels). Figure 28a is a cross-valley profile perpendicular to flow, near the dewatering line. Figure 28b is a cross-valley profile of wells perpendicular to flow, approximately 1200 ft upgradient of the barrier. Figure 29 is a profile down gradient (parallel to flow), from near 9th Avenue (well 23006) to about 400 ft upgradient of the barrier (well 24057). All of the indicator wells are within the alluvium-filled valley between the Denver highs.

60. The water levels for January 1985 (2nd quarter) are consistently higher than the levels for the other three quarters in the vicinity of the boundary to about 1000 ft upgradient (south) (see profiles, figures 28 and 29). Water levels for April 1985 (3rd quarter) are generally higher than 1st and 4th quarters. Maximum difference from quarter to quarter of FY 85 is about 2 ft. Farther upgradient, south of well 23004, the water levels change little from quarter to quarter (Figure 29). Maximum water level difference from quarter to quarter FY 85 south of well 23004 is only about 0.3 ft. The difference in quarterly water levels is most pronounced east of "D" Street (Figure 28).

61. The trend of higher levels in winter and spring continues in FY 86. Figure 30, the FY 86 profile near and upgradient of the dewatering line and analogous to Figure 28, illustrates the continuation of the seasonal trend (high winter and spring, low summer and fall). However, a break in the trend occurs in the 1st quarter of FY 86 (Figure 30) on the eastern side of the boundary, where 1st quarter (Fall) water levels are about one foot higher than 1st quarter levels for FY 85 and as high as winter/spring levels. The other three quarters of FY 86 follow the seasonal trend. The reason for the locally high 1st quarter levels is not apparent. Maximum difference in quarterly water levels for FY 86 is also about 2 ft. Figure 31 is the down-valley profile for FY 86.

62. Figures 28 through 31 show that the maximum difference in water levels from quarter to quarter occurs near the barrier. Presumably the greater water level fluctuation near the barrier is a result of operations in

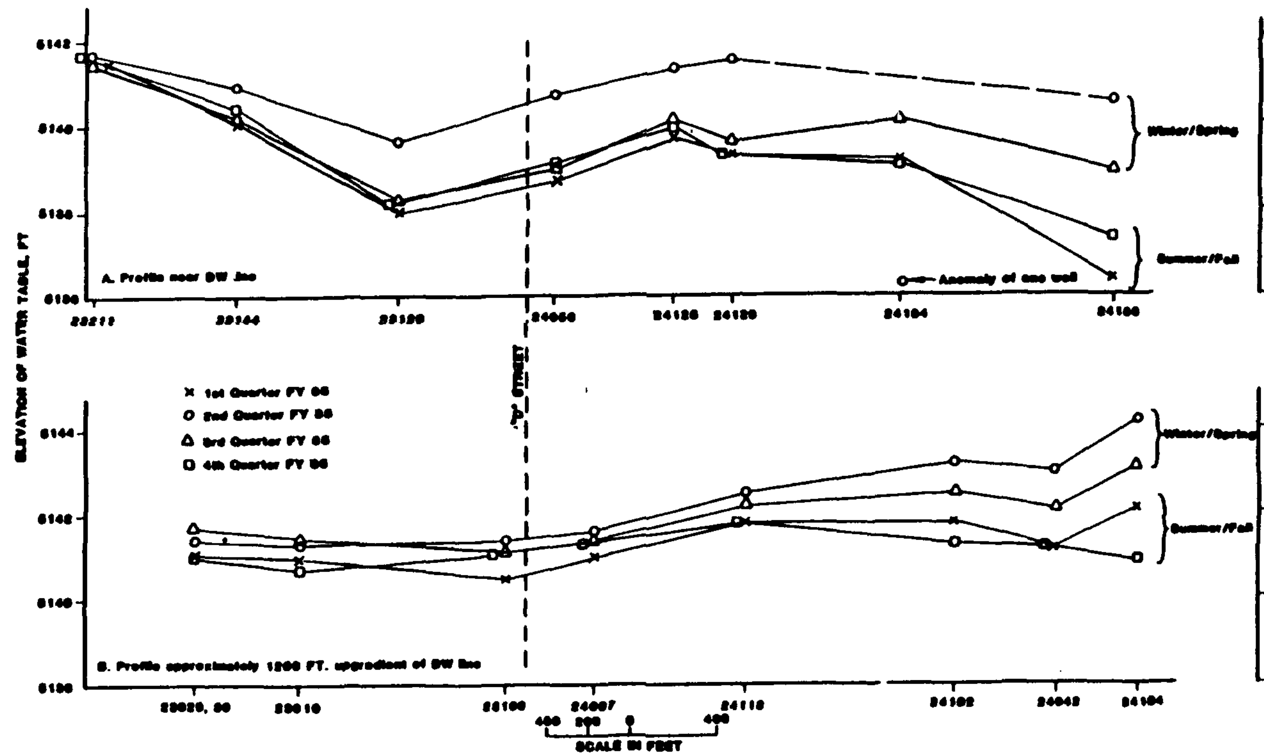


Figure 28. Cross-valley profiles of water table elevations for indicator wells, North Boundary FY 85

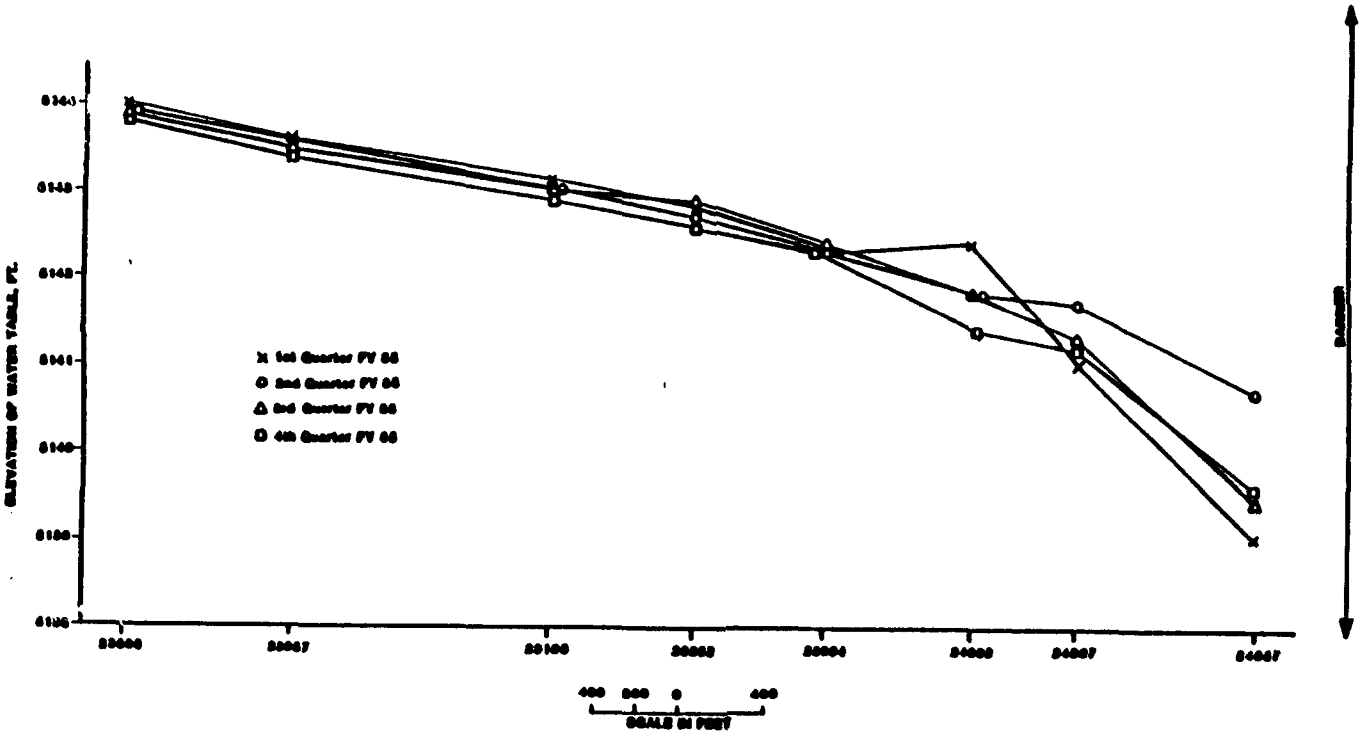


Figure 29. Down-valley profile of water-table elevations for indicator wells, North Boundary, FY 85

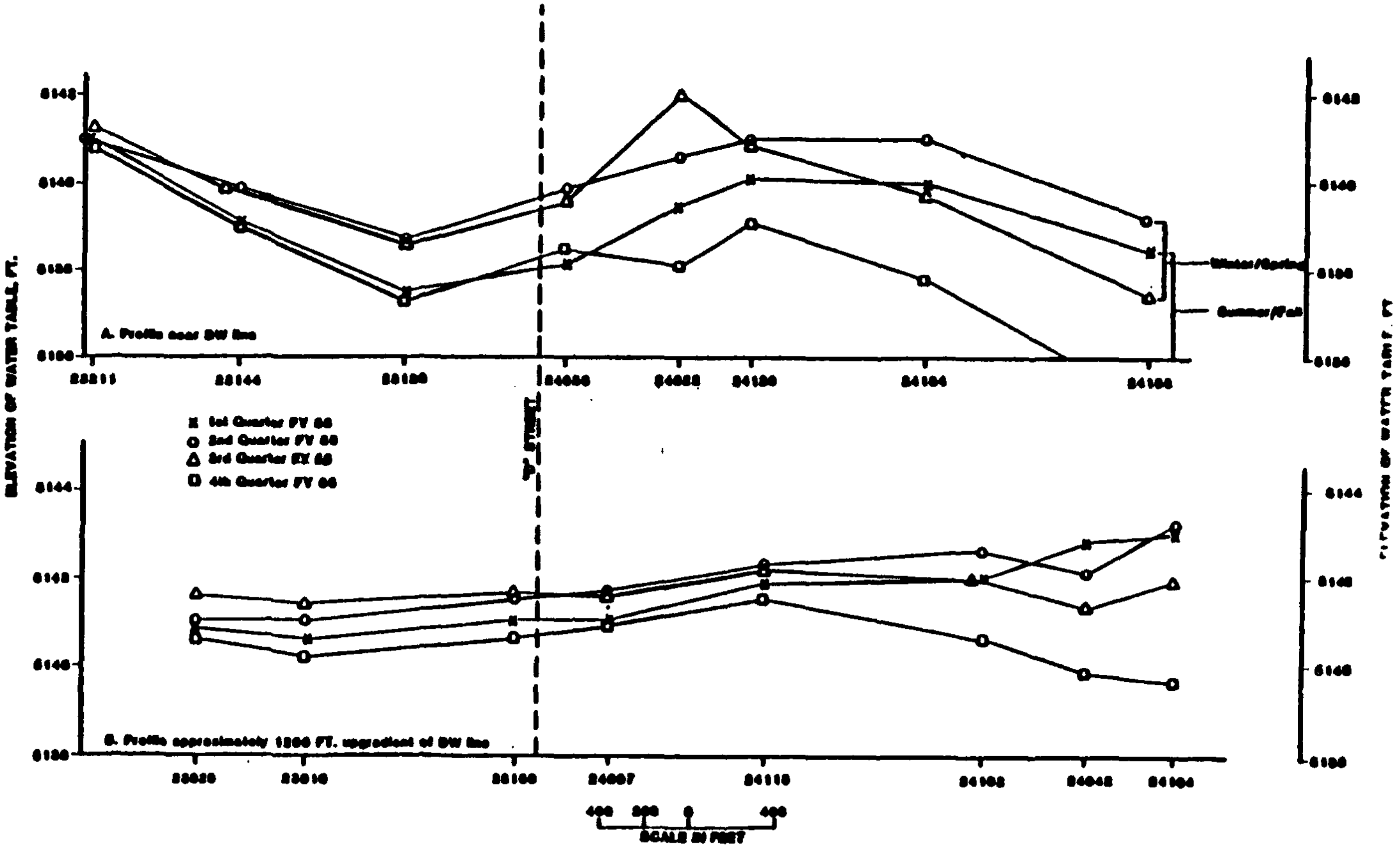


Figure 30. Cross-valley profile of water table elevations for indicator wells, North Boundary FY 86

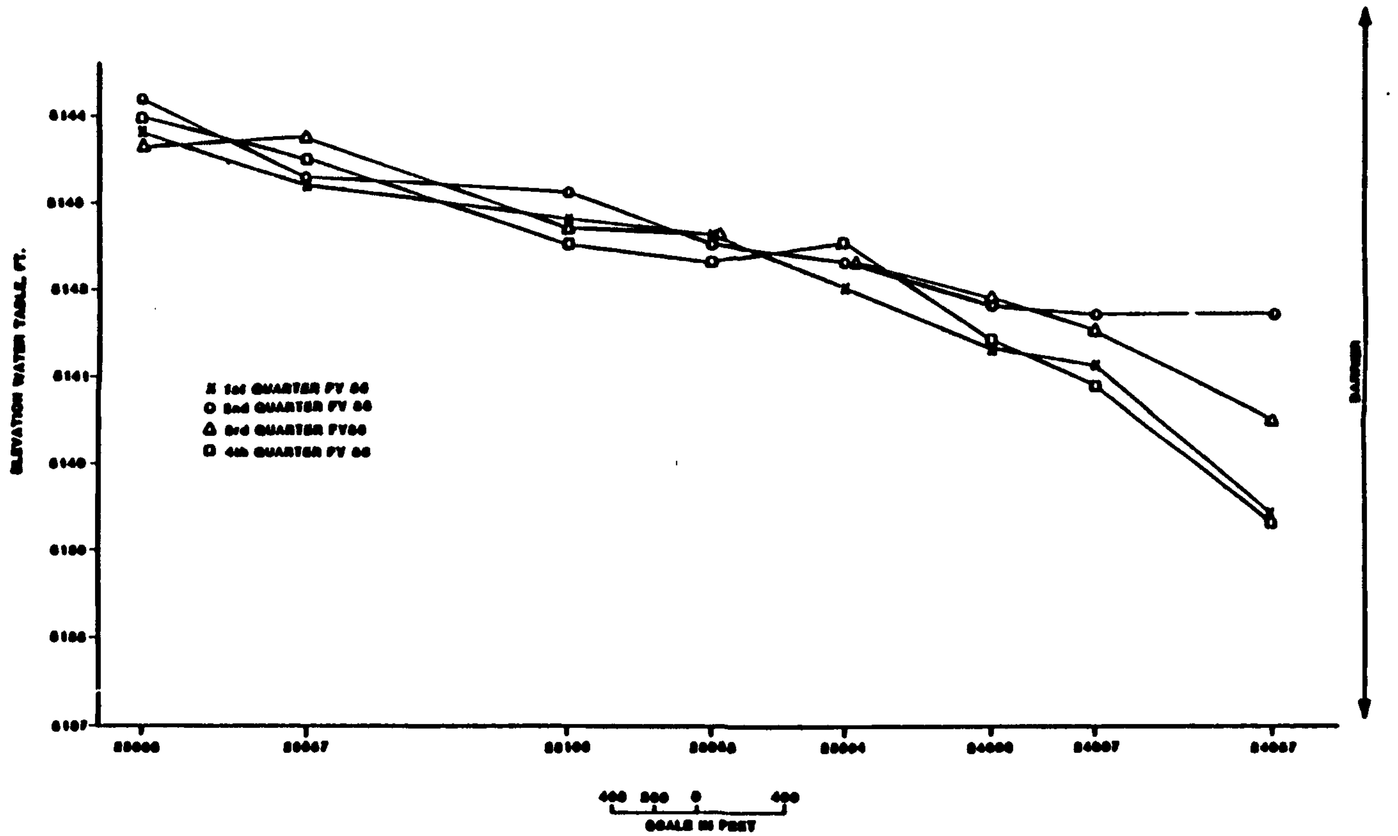


Figure 31. Down-valley profile of water-table elevations for indicator wells, North Boundary, FY 86

the ground-water discharge/treatment/recharge system. Problems in maintaining discharge and recharge in the winter months of FY 85 and FY86 help to explain higher water levels in winter/spring as the ground water builds up behind the barrier. Probable causes of water level changes are discussed in more detail later.

63. The general reaction of the north boundary water table to implementation of the barrier system can be visualized on Figure 32, a composite down-valley profile of water levels (similar to Figures 29 and 31). The upper dashed profile of Figure 32 represents 1979 post-pilot, pre-primary system water levels for the indicator wells (data from Thompson et al. 1985). The lower dashed profile represents February-March 1983 post-primary system water levels (Thompson et al. 1985). The FY 84 water levels from Thompson et al. (1985) and the FY85-86 data from this report are also represented. The water levels at the indicator wells are from monitoring records where available, or from water level contour maps where necessary.

64. The 1979 water level profile is 1 to 2 feet higher than the post-system levels south (upgradient) of well 23004 and probably reflects the condition of the relatively undisturbed water table prior to the implementation of the primary barrier and dewatering wells. The 1979 levels possibly also reflect aquifer recharge from the use of Basin C upgradient of the north boundary. By February-March of 1983 the water table was apparently drawn down to the levels shown by the post-primary profile of Figure 32, a level generally lower than previous or current levels. The low 1983 levels probably are a result of start-up of the primary system and operation of the dewatering wells along the barrier. The profile of Figure 32 indicates that after 1983 the water table "stabilized" to a range of levels generally between the upper (1979) and lower (1983) levels.

65. It is not known how much the water levels were affected by storm events, but the maximum water levels plotted for FY 84 of Figure 32 coincide closely with major storm (flooding) events in April 84 reported in Thompson et al. 1985. The flood events may account for the FY 84 levels being generally higher than the FY 85 and FY86 levels.

66. Analysis of water level changes from water level contour maps. The ground water level maps (Plates 1 through 8) illustrate general ground water elevation and flow trends for FY 85 and FY 86 in the area of the North Boundary System. A chronological comparison of maps through the two years

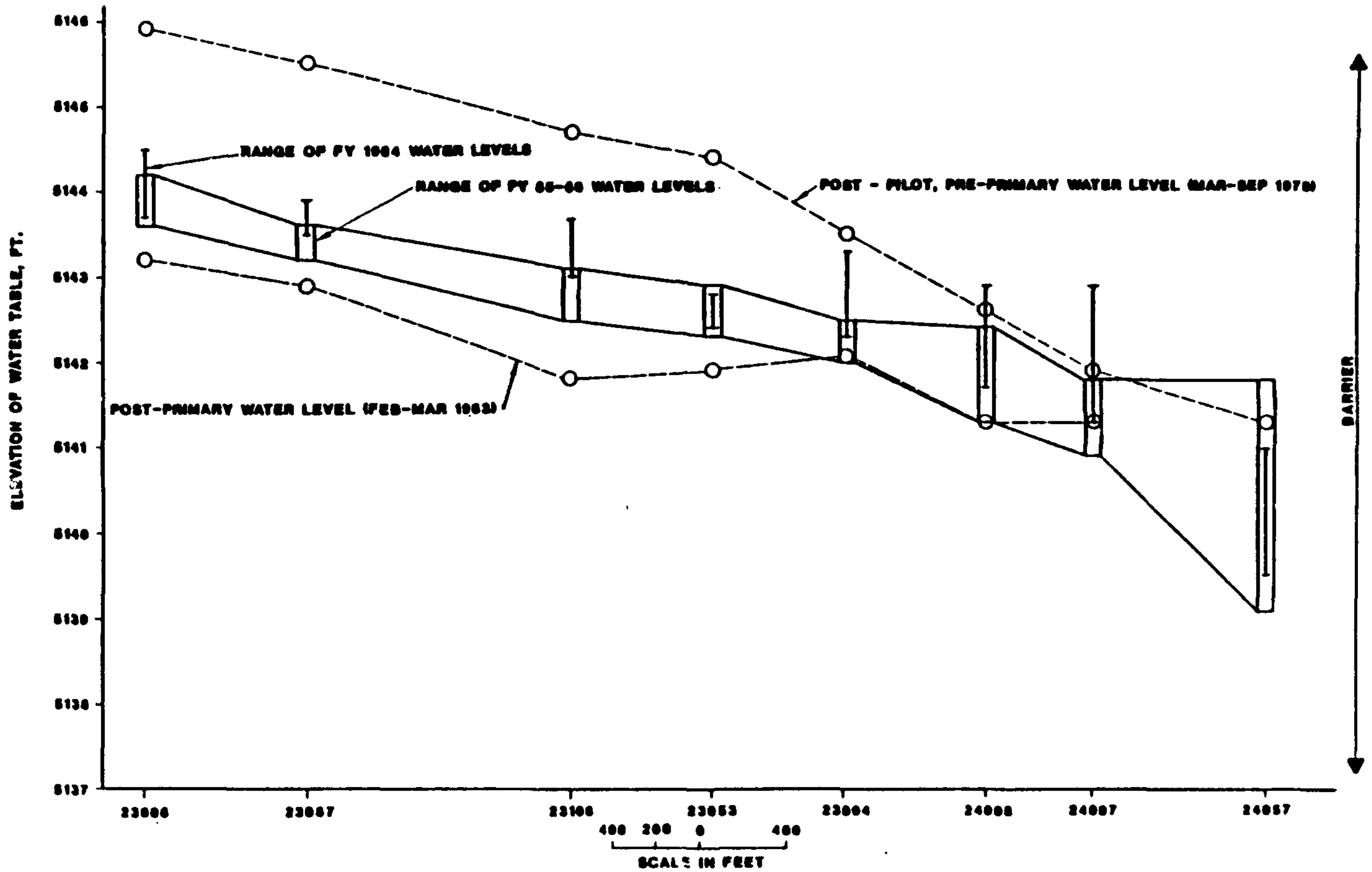


Figure 32. Composite down-valley profile of water-table elevations for indicator wells, 1979-1986, North Boundary

indicates a seasonal, cyclic movement of the ground water levels. In the 2nd quarter of each FY, Plates 2 and 6, the 5140-ft contour tends to approach the barrier (move north) whereas, in the 4th and 1st quarters of FY 85 and FY 86, respectively, (Plates 1, 4, 5 and 8) the 5140-ft contour tends to retreat south away from the barrier (north-moving contours reflect rising water level; south-moving contours reflect falling water level). This is also true, to a degree, for FY 84 (Thompson et al. 1985). Generally, for FY 85 and FY 86, although cyclic movements are occurring, the 5140- ft contour moves gradually south. By the 4th quarter FY 86 it is at its southernmost extent for the FY 84-86 period. The trend can be observed for the eastern and western portions of the area south of the barrier although it is more consistent and pronounced in the east (near wells 24-103, 104, 105 and 106) than in the west (near well 23-10). The 5140-ft contour in the central portion of the area south of the barrier (along and just east of D street) also tends to move south (near well 24-101) but ends up in approximately the same position for 1st quarter 1985 and 4th quarter 1986.

67. Movement of an intermediate contour, 5142-ft, in the areas south of the system, verifies this general change in ground water level. The contour consistently trends east-west from near well 11 in Section 23 to just north of the sewage treatment pond in Section 24. By the last quarter of FY 86, the 5142-ft contour, like contour 5140-ft, has receded south to the central portion of the sewage pond in the east and below well 23-11 in the west.

68. The 5145-ft contour roughly marks the boundary between the steep gradients in the southeastern part of Section 24 and the flatter gradients northwest toward the central part of the boundary system. Throughout FY 85 and 86, 5145-ft consistently runs east just south of and roughly parallel to 9th street to its intersection with D street, then angles northeast toward the southeast corner of the sewage treatment pond thence to just south of well 24-110. Again the 5145-ft contour is at its southernmost extent in the area of the pond for the fourth quarter of FY 86. Also, during FY 84-86, the isolated area of ground water level greater than 5145 ft in the western portion of Section 23 has moved south from near well 23-59 to near well 23-141.

69. Observation of contours 5140, 5142 and 5145-ft for FY 84 (Thompson et al. 1985) and FY 85-86, Plates 1 through 8, indicates a general ground water lowering upgradient of the system, somewhat masked by seasonal cycles. The lowering trend is most pronounced in the eastern area of the aquifer

upgradient of the system (central and eastern portions of Section 24) but a similar trend occurs in the western area upgradient of the system (central and eastern portions of Section 23). The movement of contours in the central part of the area, upgradient of the system along and somewhat to the east of D street, is less pronounced. This would result from the general ground water flow trend of the area. That is, flow has historically been to the northwest in Section 24 and to the northeast in Section 23. Convergence of flow in the central area upgradient of the system and the flow of ground water along the major valley which is near and roughly parallel to D street between sections 23 and 24 would account for less pronounced indications of ground water lowering in the central area upgradient of the system.

70. Influences on ground water level changes. System operation (flow rates) and precipitation were the major influences on ground water levels in the area of the system during FY 85 and FY 86. This section summarizes the system flow rates and precipitation amounts for FY 85 and FY 86 and for prior years for which data were available and discusses their probable influence on water levels.

71. System operations. Figure 33 is a plot of average flow rate in gpm for the system for the weeks of FY 85 and 86. Figure 33 indicates, with a few exceptions, consistent flow rates of 200 to 300+ gpm except for two periods. For those two periods, Dec-Jan 1984-85 and January-April 1986, flow rates decrease considerably (approximately 50 gpm for December-January 1984-1985 and 150 gpm for January-April 1986). These low flow periods, particularly December-January 1984 and 1985, can cause ground water levels to rise, considering other influences held constant. Figures 28 and 29 and Plate 2 confirm relatively high ground water levels in the vicinity of the barrier for 2nd quarter FY85 (January-February ground water level readings), as do Figures 30 and 31 and Plate 6 for the 2nd quarter FY86 (March ground water level readings).

72. Maps for the 1st and 4th quarters FY 85 and 4th quarter FY 86 are based on data taken after relatively long periods of higher flow rates (Figure 33 of this report and Figure 5 of Thompson et al. 1985). The maps reflect lower ground water levels compared to other quarters of FY 85 and 86. The discussion in paragraphs 66-69 concerning analysis of water level changes from water level contour maps suggested a trend to lower ground water levels

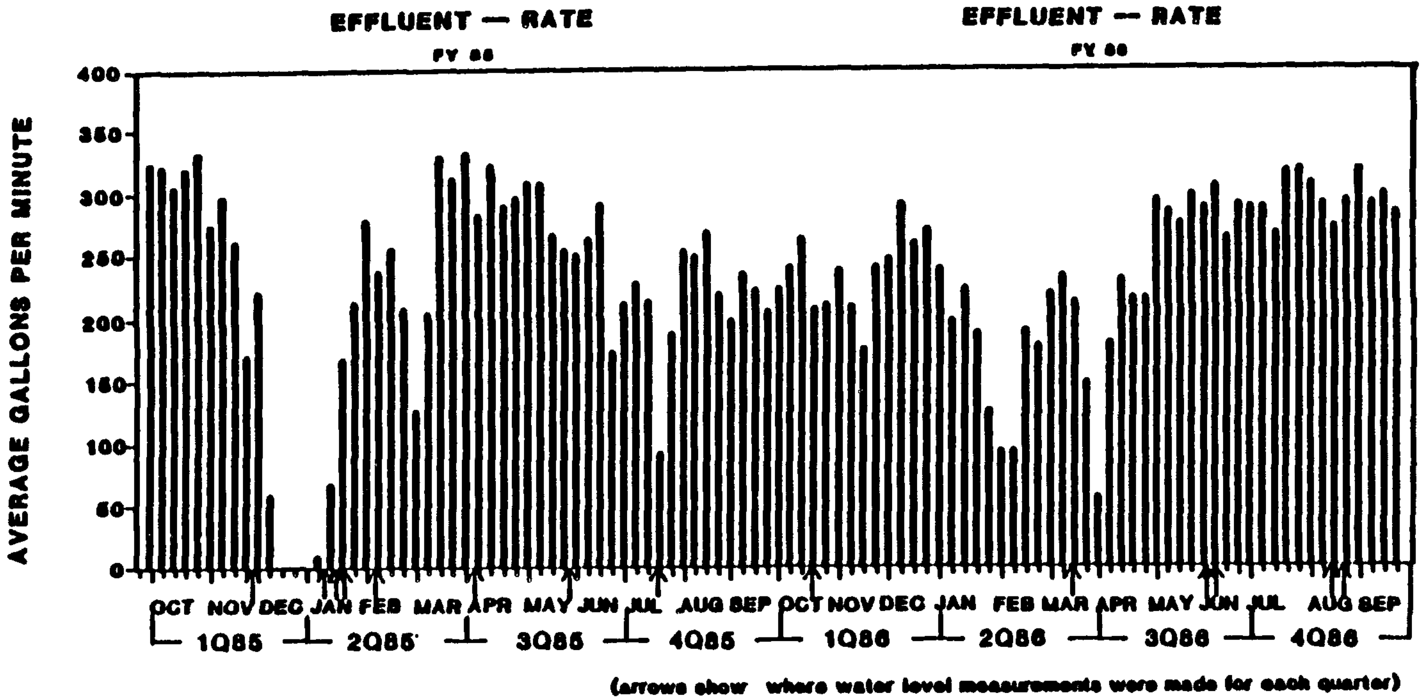


Figure 33. Effluent flow rates for North Boundary system for FY 85 and 86, weekly compilation.

with time as a result of system operation. The low 4th quarter FY 86 levels are believed to be a result of a gradual drawdown trend accentuated by high pumping rates for the late FY 86 time period. The trend toward lower levels with time (modified by seasonal fluctuation) would be expected to continue, assuming late FY 86 system flow rates are maintained.

73. Seasonal Precipitation for FY 85 and 86. Precipitation records for Rocky Mountain Arsenal near the North Boundary System were not available for the period of this study. However, the National Weather Service at Stapleton Airport supplied monthly precipitation amounts for their observation station located just south of the arsenal (see Figure 34). The rainfall records, while not necessarily reflecting local storm events (the station is approximately 5-7 miles south of the North Boundary System), provide general indications of wet and dry seasons for each year and for the wetter and drier portions of FY 85 and 86. The wet months of FY 85 and 86 were April through September and the drier months were October through March (a general trend from FY 81 through 86). Assuming a relation between precipitation and ground water level, the described precipitation sequence would be expected to cause ground water levels to be higher in the 4th quarter (July-September) and lower in the 2nd quarter (January-March), all other influences remaining constant. Reviewing Figures 28,29,30 and 31 and Plates 2,4,6 and 8, however, indicates that ground water levels are relatively higher in the 2nd quarters and lower in the 4th quarters in the vicinity of the barrier. Therefore, for FY 85 and 86, major variations in system flow rates had a greater influence than seasonal precipitation on ground water levels in Sections 23 and 24 south of the barrier.

74. Effects of Annual Precipitation and System Operations for FY 81 through 86. Precipitation records for FY 81 through 86, Table 4 and Figure 34, show that FY 81 and 82 were relatively dry years followed by three relatively wet years, FY 83, 84 and 85, followed by a relatively dry FY 86 (average precipitation for FY 71 through FY 86 is 15.0 inches/year). The profiles in Figure 32 reflect the above precipitation data (except for the 1979 profile). The lowest profile of Figure 32, Feb-Mar 1983, shows ground water levels after two dry years and prior to the major precipitation for that year (Figure 34). The range of FY 84 ground water levels is generally higher than FY 85 and 86. The FY 84 levels probably reflect the higher precipitation in the last half of FY 83 and FY 84 and the lower average system flow rates

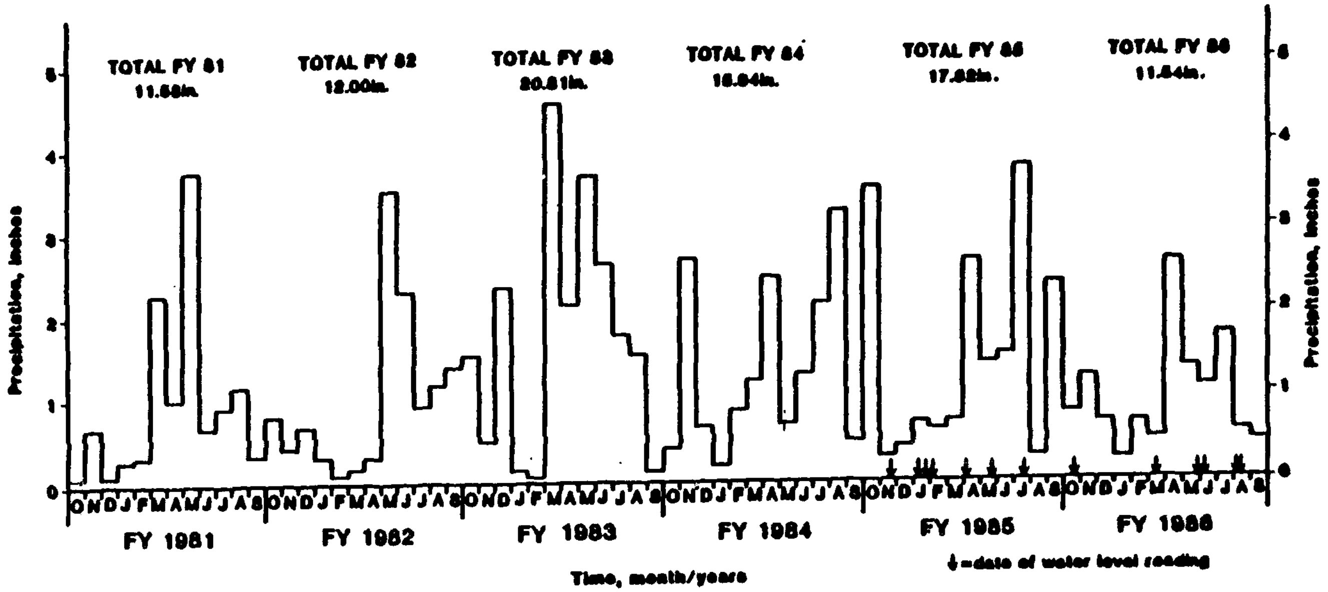


Figure 34. Precipitation measured by National Weather Service at Stapleton Airport, 1980-86.

Table 4

Precipitation at Stapleton Airport (Source, National Weather Service)

Fiscal Year	Total Precipitation, in.
1981	11.6
1982	12.0
1983	20.8
1984	15.9
1985	17.8
1986	11.5

for FY 84 (Figure 5 of Thompson et al. 1985). The gradual decrease in ground water levels over FY 84-86 primarily reflects the overall high system flow rates for this period. The flow rates apparently more than offset the higher precipitation of FY 85. Thus, given the precipitation and trend of ground water levels, the dewatering rates (Tables 2 and 3) are slightly exceeding ground water flux through the alluvial aquifer toward the system. This ground water flux is estimated to be 200-250 gpm for FY 85-86.

75. Water levels north of the barrier. Water levels north (down-gradient) of the north boundary barrier are discussed apart from those upgradient because of the effect of the barrier on ground water flow. The steep gradient across the barrier, interpreted from the water level maps, indicates that flow is relatively discontinuous across the barrier, i.e. that the barrier is indeed a very low permeability boundary. Water level data off-post (north of East 96th Avenue) are sufficient for contouring only for the last three quarters of FY 86. Data for off-post wells are contoured for Plates 6, 7, and 8. The water levels for the few off-post wells monitored prior to 2nd quarter FY 86 are noted on the FY85 and 1st quarter FY 86 water level maps but are not contoured.

76. Water level contours for FY 85 and FY 86 immediately north of the barrier indicate greater variability in water levels and steeper hydraulic gradients than immediately south of the barrier. Water levels tend to be higher near the bog, east of D street, and near the west end of the barrier. (For example, see Plates 5 and 6.) Continuing problems with recharge of

treated water through the recharge wells has necessitated recharge via the bog; thus, causing low ground water levels away from the bog area and relatively higher ground water levels near the bog.

77. Ground water contour maps for earlier years (Thompson et al. 1985) indicate historically (before system expansion) higher water levels have been present at the west end of the system. The alluvium there is composed of low permeability silts and clays overlying claystone of the Denver Formation. Higher water levels would be expected because of restriction to flow through the low permeability soils. Figure 35, a geologic cross section through the recharge wells (from Thompson et al. 1985), illustrates the location of these low permeability soils.

78. North of East 96th Avenue (off-post), monitoring wells are sparsely located and permit only coarse contouring of the water table generally along and near First Creek in Sections 13 and 14. Water level contours off-post are at 5-ft intervals. High water levels near the bog probably allow the water table to override the influence of First Creek as a local base level. Westward (down valley), however, the contours and the gradient direction appear to be influenced by the presence of First Creek, because the contour lines "V" upstream (as indicated by the limited number of wells) and the gradient generally parallels First Creek. While the limited data gives the previously mentioned trend they do not allow definition of areal ground water flow north of the RMA boundary. Little is known about seasonal effects of First Creek on ground water levels and direction. For example, First Creek is normally dry for significant periods each year. Further definition of ground water flow in this area will be provided by the PM, RMA remedial studies being conducted at RMA.

Distribution of Contaminants

Background

79. Ground water contamination at the north boundary of RMA is a result of the historical disposal of wastes from various activities conducted on RMA. The contaminants found in the ground water at the boundary can be associated with operation of the disposal basins, the sewage treatment plant, and the chemical and sanitary sewers. Historical data on the contaminants are discussed in Thompson et al. (1985).

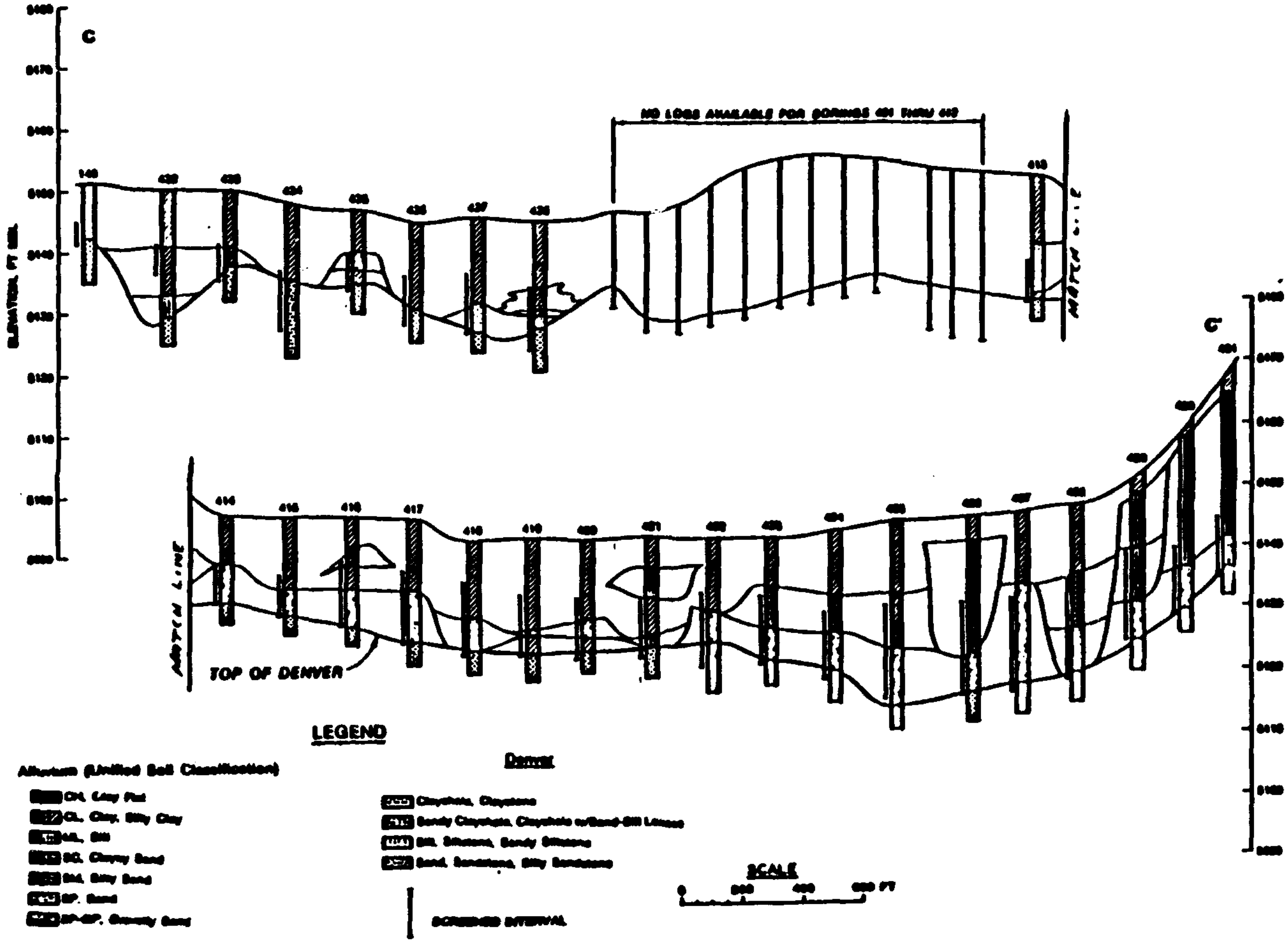


Figure 35. Geologic cross section through recharge wells, North Boundary (reproduced from Plate G-05, Thompson et al. 1985).

80. In order to illustrate the changes in the distribution of the contaminants along the north boundary during FY85 and FY86, a series of isoconcentration maps have been developed for each of the major contaminants (Volume II Plates 10 thru 81). In general, contaminant concentration data were collected quarterly during each fiscal year (FY). The data collection period associated with each individual map is identified on the respective plate. During certain quarters, particularly the 2nd and 3rd quarters of FY86, only limited data were available for plotting isoconcentration maps. As a result, the maps for these periods were constructed using the previous maps as a guide for contouring. The contour lines thus generated are depicted as dashed lines.

81. It should be noted that contaminant concentration data were not available for the same wells during each quarter because of changes in the sampling program over the study period. The resulting deletion or addition of data at a certain well on the map can result in changes in the position of a particular isoconcentration line between monitoring periods. Thus, changes in the positions of isoconcentration lines over time may not necessarily represent contaminant plume movement. Therefore, each map should be viewed as a snapshot in time of the general distribution of a contaminant for that monitoring period and not necessarily as an absolute indicator of contaminant migration.

82. In reviewing the maps, it becomes evident that the contaminant distributions tend to follow a general pattern, the buried alluvial river channel evident in the bedrock and groundwater maps. The distributions of the different contaminants vary somewhat probably due to the location of the source and their migration characteristics. However, the overall pattern for the North Boundary System study area is that of a "dogleg" originating in the vicinity of Basin F, northeast across 9th Avenue, and then north to the barrier. For a more complete picture of regional contaminant distributions refer to the results of PM, RMA Task 4 remedial investigation (RIC No. 87013R01).

DBCP

83. The DBCP isoconcentration maps for FY85 and FY86 are presented as Plates 10 through 17. Concentrations of DBCP in the study area range from below detectable level to over 40 ppb. Concentration contours of 0.2, 0.5, 1, 5, 10, 15, 20, 25, and 40 ppb are shown on each map as required.

84. In the study area, DBCP is found distributed from just east of the northeast corner of Basin F, northeast across 9th Avenue and D Street to the

barrier. The area of DBCP contamination tends to spread somewhat to the east at the barrier during several of the monitoring periods. The overall distribution of DBCP did not change much over the study period other than a slight narrowing of the contaminated area in the southeast corner of Section 23.

85. During the 1st quarter of FY85, the highest concentrations of DBCP, over 10 ppb, were found centered around 9th Avenue, just east of D Street, and just south of the barrier. During the 2nd quarter of FY85, slightly lower concentrations were found northeast of 9th Avenue and an area of high concentration, in excess of 20 ppb, was found to the east of the northeast corner of Basin F. This is an area for which data were not available during the 1st quarter.

86. During the 3rd quarter of FY85, the DBCP distribution narrowed near the barrier and the concentrations found just west of D Street increased slightly. By the 4th quarter of FY85, the width of the area of distribution decreased in the east-central part of Section 23 and the concentrations in the area of D Street decreased somewhat. The DBCP concentration east of the northeast corner of Basin F increased to over 40 ppb. In addition, a concentration of DBCP in excess of 1 ppb was found in the sample taken from well 24115. No concentration of DBCP was found in this area during the 3rd quarter, but had been found in the 1st and 2nd quarter. The contours around well 24115 were constructed differently for the 4th quarter than for the 1st and 2nd because no DBCP was found immediately north or west of well 24115 in the 4th quarter.

87. By the end of the 1st quarter of FY86, the area of DBCP distribution in the east-central part of Section 23 widened. The high concentrations east of Basin F do not appear on the map due to a lack of data. The DBCP concentrations in the area of well 24115 fell to below 0.2 ppb. A continuous area of DBCP concentrations in excess of 5 ppb was found south of the barrier extending to just south of well 24029. The maps for the 2nd and 3rd quarters of FY86 are similar in appearance. It should be noted that the data were very limited for this period. Data were again collected for wells located east of the northeast corner of Basin F and an area of concentrations in excess of 20 ppb appears on both maps. By the 3rd quarter of FY86, offpost data north of the barrier became available. An area of DBCP concentrations in excess of 0.5 ppb was found just north of the intersection of 96th Avenue and Peoria Street.

88. By the 4th quarter of FY86, the distribution of increased DBCP concentrations to the east of Basin F shifted slightly to the north. An area of DBCP concentrations in excess of 0.2 ppb was found immediately north of the sewage treatment pond. The DBCP concentrations north of the system decreased slightly. Comparing this most recent distribution plot with the historical plots presented in the FY84 report, the shape and size of the area of DBCP distribution has changed little since the system was installed. The highest concentration values in the center of the distribution area appear to have decreased by 5 to 10 ppb. The most recent data also indicate the presence of a DBCP plume originating in vicinity of well 26133.

DIMP

89. The DIMP isoconcentration maps for FY85 and FY86 are presented as Plates 18 through 25. DIMP concentrations range from less than 50 ppb to over 2,000 ppb. Concentration contours of 50, 100, 500, 1,000, 2,000, 3,000, and 4,000 ppb are shown on each map as required.

90. In the study area, DIMP is generally found distributed from the northeast corner of Basin F, northeast across 9th Avenue to D Street, and then north to the system. The DIMP distribution changed somewhat over the study period. In FY85, concentrations of DIMP above 1000 ppb were found in several noncontinuous areas between Basin F and the system. By FY86, DIMP concentrations in excess of 1000 ppb were found in a continuous area from Basin F to the system.

91. During the 1st quarter of FY85, DIMP in excess of 1000 ppb was found in two separate areas. The first is in the southeastern quarter of Section 23 and includes a small area in the vicinity of well 23102 where a concentration in excess of 2000 ppb was found. The other area is much smaller and is located immediately south of the system to the west of D Street in Section 23. Concentrations of DIMP in excess of 500 ppb were found extending from Basin F to the system. The distribution found in the 2nd quarter of FY85 is very similar to that of the 1st quarter. The shape of the large area within the 1000 ppb contour changed somewhat and no concentrations in excess of 2000 ppb were found.

92. The DIMP distribution in the 3rd quarter of FY85 was very similar to the first two quarters. An area of concentrations in excess of 2000 ppb reappeared in the southeastern quarter of Section 23. This area is somewhat larger than the one found during the 1st quarter. By the 4th quarter of FY85,

the area of distribution of DIMP over 500 ppb had narrowed somewhat. The areas enclosed by the 1000 ppb and 2000 ppb contours in the southeastern quarter of Section 23 are smaller than they were in the 3rd quarter.

93. During the 1st quarter of FY86, the area of DIMP concentrations in excess of 1000 ppb extends to the system. A small area of concentrations in excess of 2000 ppb is still observed in the southeastern corner of Section 23. The contour lines from 9th Avenue south are dashed due to the limited amount of data available for that area. During the 2nd quarter of FY86, the distribution of DIMP immediately north of Basin F appears to be somewhat wider than in the previous quarter. The area of concentrations in excess of 2000 ppb disappeared.

94. The contours developed from the 3rd quarter data are very similar to those from the 2nd quarter. There are no significant changes in DIMP distribution immediately north of Basin F. During the 3rd quarter of FY86, offpost data on DIMP concentrations became available and was used to develop contours north of the system. Concentrations in excess of 4000 ppm were found adjacent to Highway 2 in Section 14. The contours give the appearance of the trailing edge of a plume. The distribution of DIMP in the 4th quarter of FY86 is very similar to the 3rd quarter. The area of concentrations in excess of 1000 ppb widened somewhat in the east-central part of Section 23. Additional data from the area north of system resulted in an enlarging of the offpost DIMP distribution from that found during the 3rd quarter. The maximum concentration found offpost during the 4th quarter was in excess of 3000 ppb.

95. Comparing the most recent distribution plots with the historical plots presented in the FY84 report, the shape and location of the area of DIMP distribution has changed little since the system was installed. However, the highest concentrations of DIMP found in the area have decreased since the FY79 monitoring period. The historical highly concentrated plumes of DIMP immediately adjacent to the northeast corner of Basin F are not evident in the recent plots.

<u>DCPD</u>

96. The DCPD isoconcentration maps for FY85 and FY86 are presented as Plates 26 through 33. DCPD concentrations range from less than 10 ppb to over 2,000 ppb. Concentration contours of 10, 100, 500, 1,000, and 2,000 are shown on each map as required. It should be noted that DCPD is a volatile organic

and thus the sample collection and handling technique used for a particular sample can effect the analytical result.

97. In the study area, DCPD is generally found distributed east of the northeast corner of Basin F, across 9th Avenue, northeast to D Street, and then north to the system. The distribution of DCPD varied over the study period with some significant fluctuations in concentrations occurring. Some of these fluctuations may be due to changes in sampling techniques during the study period.

98. During the 1st quarter of FY85, the area of DCPD concentrations in excess of 100 ppb ends immediately east of D Street in the area of well 24049. The 10 ppb contour extends north from that point towards the system. A small area with concentrations in excess of 1000 ppb is located immediately north of 9th Avenue. By the 2nd quarter of FY85, the area of concentrations in excess of 500 ppb has become segmented with one area in the south-central part of Section 23 and the other along D Street in the northern halves of Sections 23 and 24. The 500 ppb contour now extends to just south of the system. Two small areas of DCPD concentrations in excess of 1000 ppb were found associated with wells 23095, in the southern part of Section 23, and 23123, in the northeastern corner of Section 23.

99. By the 3rd quarter of FY85, the northern area surrounded by the 500 ppb contour had decreased in size leaving two small areas adjacent to wells 23123 and 23004. No concentrations in excess of 500 ppb were found in the southern part of Section 23. During the 4th quarter of FY85, the DCPD distribution just south of the system widened. A larger area of concentrations in excess of 500 ppb appeared just south of the system with a concentration in excess of 2000 ppb found at well 23160.

100. The DCPD distribution in the 1st quarter of FY86 is very similar to the 4th quarter of FY85. The area of high concentrations just south of the system appears to have moved to the north with a general narrowing of the distribution in this area. During the 2nd quarter of FY86, an area of DCPD concentrations in excess of 500 ppb developed northeast of Basin F. The area of higher concentrations just south of the system that was evident in the 1st quarter does not appear in the second quarter. This can probably be attributed to the lack of data available in this area during the 2nd quarter of FY86.

101. The onpost DCPD distribution in the 3rd quarter of FY86 is essentially identical to the 2nd quarter. The offpost data available during this quarter resulted in a distribution of DCPD north of 96th Avenue along Peoria Street. The highest concentration found was in excess of 500 ppb. The DCPD distribution south of the system in the 4th quarter of FY86 is very similar to the 3rd quarter distribution. The 500 ppb contour stretched slightly to the north. An area of concentrations in excess of 500 ppb was again observed south of the system. The offpost distribution changed little with the exception of an increase in the area bounded by the 10 ppb contour.

102. In comparing the most recent DCPD distribution plots with the historical ones, the shape and location of the distribution has remained fairly consistant since installation of the system. However, as with the other contaminants, the areas of highest concentrations have moved around and decreased slightly since the FY79 monitoring period.

Sulfur Compounds

103. The organo-sulfur compounds identified in the study area include p-chlorophenylmethylsulfide, -sulfoxide, -sulfone. The concentrations of these three compounds have been added together to generate combined isoconcentration maps that are shown in plates 34 through 41. Combined concentrations of organo-sulfurs ranged from below 50 ppb to over 1,000 ppb. Concentration contours of 50, 100, 150, 500, and 1,000 ppb are shown on each map as required.

104. In the study area, the organo-sulfurs are found distributed from the northeast corner of Basin F, northeast across 9th Avenue to a point halfway to the system, east to D Street, and then north to the system. The distribution of the sulfurs varied somewhat over the study period. The area of distribution near the center of Section 23 widened and spread to the north. The area enclosed by the 100 ppb contour spread slightly to the north over the length of the study period.

105. During the 1st quarter of FY85, the highest concentration of organo-sulfurs, in excess of 500 ppb, was found north of 9th Avenue in the vicinity of well 23095. An area of concentrations in excess of 150 ppb stretches from Basin F to just east of D Street. For the 2nd quarter of FY85, the distribution is similar to the 1st quarter. However, the area of concentrations in excess of 500 ppb near 9th Avenue has increased in size and a composited concentration in excess of 1000 ppb is located in the vicinity of well 23095.

106. By the 3rd quarter of FY85, the area enclosed by the 500 ppb contour near 9th Avenue has disappeared and only a small area associated with well 23052 was identified with a concentration in excess of 500 ppb. Concentrations near the system decreased slightly. An additional area near the center of Section 23 was found to contain concentrations in excess of 50 ppb. The 4th quarter distribution is similar to the 3rd quarter with the exception that a large area of concentrations in excess of 500 ppb was again identified stretching from 9th Avenue to near D Street.

107. During the 1st quarter of FY86, the area inclosed by the 50 ppb contour in the center of Section 23 retreated back to the south. The distribution became discontinuous in the northwestern corner of Section 24. Concentrations in that area decreased to below 50 ppb. The distribution found in the 2nd quarter of FY86 was essentially the same as in 1st quarter. The 50 ppb contour lines were continued to the system although the data in this area was very limited.

108. Additional data available in the 3rd quarter of FY86 resulted in an increase in the area bounded by the 500 ppb contour. An area of combined concentrations in excess of 1,000 ppb was found immediately east of the northeast corner of Basin F. The offpost data available in the 3rd quarter of FY86 indicates a small area of concentrations in excess of 50 ppb immediately north of the intersection of 96th Avenue and Peoria Street. During the 4th quarter of FY86, the combined organo-sulfurs distribution widened and advanced into the central part of Section 23. The area of concentrations in excess of 500 ppb expanded to the east while the 100 ppb and 150 ppb contours advanced slightly to the north. The offpost distribution remained essentially the same as that found in the 3rd quarter.

109. Historical organo-sulfur data in the study area are limited. The oldest isoconcentration map presented in the FY84 report is from the 2nd quarter of FY84. The size and shape of the distribution from that study period are similar to those for the FY85 and FY86 distributions. However, the highest concentrations found in the distribution appear to have increased since the FY84 study period.

Aldrin

110. The aldrin isoconcentration maps for FY85 and FY86 are presented as Plates 42 through 49. Concentrations of aldrin in the study area range from

below detectable to over 1 ppb. Concentration contours of 0.2 and 1 ppb are shown on each map as required.

111. The distribution of aldrin varied greatly over the study period. For the majority of the quarters, aldrin was found above the detectable level only in the area immediately north of the northeast corner of Basin F. During two quarters, no detectable quantities of aldrin were found in the study area. During one quarter, aldrin was found distributed from Basin F to the system. It should be noted that aldrin is found in this area only at low concentrations and therefore small changes in concentration can significantly alter the isoconcentration plots.

112. During the 1st quarter of FY85, aldrin was found in an area north of 9th Avenue along D Street. The highest concentration found was in excess of 1 ppb. During the 2nd quarter of FY85, the aldrin distribution shifted to the west. Concentrations of aldrin above the detectable level were found from 9th Avenue to the system. An area of concentrations in excess of 1 ppb is located south of the system along D Street. No detectable quantities of aldrin were found during the 3rd and 4th quarters of FY85.

113. During the 1st quarter of FY86, the distribution of aldrin originates at the northeast corner of Basin F, continues north across 9th Avenue, northeast across D Street, and then continues for a short distance to the north. No concentrations in excess of 1 ppb were found. During the 2nd quarter of FY86, the aldrin distribution is confined to an area north of the northeast corner of Basin F. A small area of concentrations in excess of 1 ppb is located just north of 9th Avenue in the vicinity of wells 23094 and 23095.

114. The aldrin distribution for the 3rd quarter of FY86 is very similar to that for the 2nd quarter. No concentrations above the detectable level were found offpost. During the 4th quarter of FY86, the area bounded by the 0.2 contour has stretched slightly to the north. The area of concentrations in excess of 1 ppb reaches from east of the northeast corner of Basin F across 9th Avenue to just south of well 23095. Offpost, concentrations of aldrin in excess of 0.2 ppb were found centered around well 23198, just north of the system, and well 37343, adjacent to Highway 2.

115. Historical data on aldrin in the study area are available back to mid-1983. A review of the available plots indicates an irradically changing distribution through the various study periods. The maximum concentrations found have not varied much over time but the location of these concentrations

has. Again, this is probably because the maximum concentrations of aldrin found are very low, in the 2 to 3 ppb range.

Endrin

116. The endrin isoconcentration maps for FY85 and FY86 are presented as Plates 50 thru 57. Concentrations of endrin in the study area range from less than 0.2 ppb to over 15 ppb. Concentration contours of 0.2, 1, 5, 10, and 15 ppb are shown on each map as required.

117. The distribution of endrin varied over the study area. For most of the quarters, the concentrations of endrin found were distributed from the northeast corner of Basin F, north-northeast to the system. During several quarters, the distribution was not continuous. There were also large fluctuations in concentrations in many areas between quarters.

118. During the 1st quarter of FY85, concentrations of endrin in excess of 1 ppb were found distributed from 9th Avenue to the system. Two areas with concentrations in excess of 5 ppb are indicated along D Street, one midway between 9th Avenue and the system, and the other immediately south of the system. During the 2nd quarter of FY85, no concentrations above 0.2 ppb were found in the southern part of Section 23. The area of highest concentration, in excess of 10 ppb, is located in the east-central part of Section 23 adjacent to well 23052. The 5 ppb contour stretches from this area, north to the system.

119. By the 3rd quarter of FY85, the endrin distribution has become discontinuous. Two areas of concentrations in excess of 1 ppb are indicated, one in the southeastern corner of Section 23 and one in the northwestern corner of Section 24. No concentrations in excess of 5 ppb were found. During the 4th quarter of FY85, the area in the southeastern corner of Section 23 increased in size. The area in the northwestern corner of Section 24 is similar to that found in the 3rd quarter. Also, a small area of concentrations in excess of 1 ppb was found adjacent to the northeast corner of Basin F.

120. By the 1st quarter of FY86, the endrin distribution has become continuous from 9th Avenue to the system. A maximum concentration in excess of 15 ppb was found in the east-central part of Section 23 in the vicinity of well 23052. It is not possible to assess the changes if any occurring during the 2nd and 3rd quarters of FY86 in the endrin distribution south of the system due to a lack of data. During the 3rd quarter, the available offpost data indicates a distribution of endrin north of the system crossing

96th Avenue, and then northwest across Peoria Street. The maximum concentration found was in excess of 1 ppb. By the 4th quarter of FY86, the higher concentrations of endrin found in Section 23 during the 1st quarter had disappeared. The onpost distribution is continuous from south of 9th Avenue, north to the system. The offpost distribution is similar to that found for the 3rd quarter.

121. Historical data on endrin in the study area are available back to mid-1983. A review of the available plots indicates a changing distribution through the varies study periods. The high concentrations of endrin, in excess of 60 ppb found in 1983 just north of 9th Avenue have disappeared. The locations of the areas of higher concentrations have moved around somewhat irradically over the various study periods.

Dieldrin

122. The dieldrin isoconcentration maps for FY85 and FY86 are presented as Plates 58 through 65. Concentrations of dieldrin in the study area range from less than 0.2 ppb to over 5 ppb. Concentration contours of 0.2, 1, and 5 ppb are shown on each map as required.

123. In the study area, dieldrin is found distributed from the northeast corner of Basin F northeast to the system. The dieldrin distribution does not have the pronounced dogleg shape that many of the other contaminant distributions exhibit. The area of distribution did not change much over the study period however there were some fluctuations in maximum concentrations in the distribution area.

124. During the 1st quarter of FY85, the highest concentrations of dieldrin, in excess of 5 ppb, were found midway between 9th Avenue and the system along D Street. An area with concentrations in excess of 1 ppb is located just north of 9th Avenue extending to the system. During the 2nd quarter of FY85, the 1 ppb contour remains in approximately the same location as in the 1st quarter. The size of the area bounded by the 5 ppb contour is reduced.

125. During the 3rd quarter of FY85, the area containing concentrations in excess of 1 ppb narrows from a point in the east-central part of Section 23 northward. No concentrations in excess of 5 ppb were found. By the 4th quarter of FY85, the area containing concentrations in excess of 1 ppb has spread back to the south. In addition, the dieldrin concentrations in the area of well 24049 have increased to over 5 ppb again.

126. During the 1st quarter of FY86, the dieldrin distribution widened and spread towards the west. An area of concentrations in excess of 5 ppm was found in the southeastern corner of Section 23. The extent of the distributions for the 2nd and 3rd quarters of FY86 are very similar. There are no details in the northern half of the study area because of a lack of data. Offpost data available during the 3rd quarter of FY86 indicates the presence of a small area of distribution of dieldrin north of the system and mostly east of Peoria Street. The onpost distribution of dieldrin during the 4th quarter of FY86 is very similar to that of the last three quarters. No concentrations in excess of 5 ppb were found. The offpost distribution stretched from the system, northwest to Highway 2.

127. Historical data on dieldrin in the study area are available back to mid-1983. A review of the available plots indicates a movement of the distribution to the east since 1983. There has also been a small decline in the concentrations found in the southern half of Section 23.

Chloride

128. The chloride isoconcentration maps for FY85 and FY86 are presented as Plates 66 through 73. Concentration of chloride in the study area range from less than 100 ppm to greater than 5000 ppm. Concentration contours of 100, 250, 500, 1,000, 2,000, and 5,000 ppm are shown on each map as required.

129. In the study area, chloride is found distributed over most of Sections 23 and 24. Chlorides occur naturally and are generally found at background levels of 100-150 ppm in alluvial ground water in the vicinity of RMA. The distribution of chloride concentrations in excess of the background levels originates at the northeast corner of Basin F, proceeds northeast across 9th Avenue to D Street, and then turns north to the system. The general location of the chloride distribution did not change much over the study period however the maximum concentrations found in the distribution fluctuated from quarter to quarter.

130. During the 1st quarter of FY85, the highest concentrations of chloride, in excess of 2000 ppm, were found in two areas. The first area is located north of the northeast corner of Basin F and extends north across 9th Avenue. The other area is a small area in the vicinity of well 23052. The area bounded by the 1000 ppm contour is continuous and continues to a point midway between 9th Avenue and the system along D Street. By the 2nd quarter of FY85, the 1000 ppm contour has moved slightly northward, the

2000 ppm contour has become continuous, and an area with chloride concentrations in excess of 5000 ppm has stretched from Basin F, across 9th Avenue, to the vicinity of well 23095.

131. During the 3rd quarter of FY85, the area of concentrations in excess of 500 ppm stretched northward to the system. The 1000 ppm contour remained in approximately the same location as the previous quarter, while the 2000 ppm contour became discontinuous and the 5000 ppm contour became isolated in the vicinity of well 23095. During the 4th quarter of FY85, the distribution returned to a shape similar to that found in the 2nd quarter. The 2000 ppm and 5000 ppm contours are continuous from Basin F northward. The northern most part of the 500 ppm contour is at the system.

132. By the 1st quarter of FY86, the chloride distribution has shifted slightly to the east. The relative positions of the contours are similar to the last quarter. The shape of the distribution and locations of the contour lines in the southern part of the study area are not clearly defined due to a lack of data. The chloride distributions for the 2nd and 3rd quarters of FY86 are probably similar to the 1st quarter but the actual locations of the 500 ppm and 1000 ppm contours in the northern half of study area could not be determined due to a lack of data. Offpost data available in the 3rd quarter of FY86 indicates a distribution of chloride concentrations above background levels north of the system. Two areas with concentrations in excess of 1000 ppm were found. One associated with well 37339, adjacent to 96th Avenue, and one associated with well 37316, adjacent to Highway 2.

133. During the 4th quarter of FY86, the northern most extention of the 1000 ppm contour is approaching the system. An area with concentrations in excess of 2000 ppm stretches from Basin F north to a point midway to the system. A concentration in excess of 5000 ppm was found associated with well 23095. The offpost distribution is similar to the 3rd quarter of FY86 with higher chloride concentrations found associated with wells 37339 and 37316.

134. Comparing the most recent distribution plots with the historical plots presented in the FY84 report, the shape and location of the area of chloride distribution has changed little since the system was installed. The maximum concentrations found in the area have not changed much since 1979.

Fluoride

135. The fluoride isoconcentration maps for FY85 and FY86 are presented as Plates 74 through 81. Concentrations of fluoride in the study area range from less than 1 ppm to greater than 20 ppm. Concentration contours of 1, 2, 3, 4, 5, 6, 7, 10, and 20 are shown on each map as required.

136. Like chloride, fluoride occurs naturally in the ground water and thus is found distributed over most of Sections 23 and 24 in the 1 ppm range. The distribution of fluoride concentrations in excess of the background levels changed over the study period. Early in FY85, the highest concentrations were found in the northwest corner of the study area. These concentrations have decreased, however, later data are now sufficient to map a plume in the vicinity of the northeast corner of Basin F. Fluoride concentrations in the northwestern part of the study area tend to be relatively higher than for the other contaminants.

137. During the 1st quarter of FY85, the highest fluoride concentrations, in excess of 7 ppm, were found along the west end of the system. The concentrations decrease from that point back to the southeast. A small area of concentrations in excess of 4 ppm is located along the northeast corner of Basin F. An area with concentrations in excess of 5 ppm is evident at the intersection of 9th Avenue and D Street. By the 2nd quarter of FY85, the area of higher concentrations along the west end of the system has moved towards the north. A small area with fluoride concentrations in excess of 6 ppm is located adjacent to well 23079. The concentrations in the area of the intersection of 9th Avenue and D Street have decreased.

138. During the 3rd quarter of FY85, a distribution of fluoride concentrations in excess of 5 ppm stretches from the northeast corner of Basin F northeast to the system. The highest concentrations found, in excess of 7 ppm, were found along the northeast corner of Basin F. By the 4th quarter of FY85, the concentration distribution had changed. An isolated area of concentrations in excess of 7 ppm is located adjacent to well 23013. A concentration in excess of 20 ppm was found associated with well 23049 just north of 9th Avenue.

139. The changes in fluoride distribution near Basin F during the 1st quarter of FY86 cannot be assessed because of a lack of data. A small area of concentrations in excess of 7 ppm was found adjacent to well 23011 northeast of the center of Section 23. During the 2nd quarter of FY86, the

available data indicates a narrow area of fluoride concentrations in excess of 10 ppm originating at the northeast corner of Basin F and continuing northeast across 9th Avenue. The distribution along the system is undefined.

140. During the 3rd quarter of FY86, the distribution northeast of Basin F is similar to that of the 2nd quarter. Available offpost data indicate a distribution of fluoride northwest of the system with concentrations generally in excess of 2 ppm. The highest concentration found, in excess of 5 ppm, was adjacent to well 37339. During the 4th quarter of FY86, an area of fluoride concentrations in excess of 10 ppm is located to the east of the northeast corner of Basin F stretching north to 9th Avenue. An area of concentrations in excess of 7 ppm is located in the northwest corner of Section 24 just south of the system. The offpost distribution is similar to that found during the 3rd quarter.

141. Comparing the most recent distribution plots with the historical plots presented in Thompson et al. (1985), the distribution of fluoride has changed significantly over the various study periods. From 1977 until the middle of FY85, the highest concentrations of fluoride had generally been found in the north-central part of Section 23 along the west end of the system. The concentrations generally decreased towards the southeast. After the 2nd quarter of FY85, the distribution changed and became more similar in form to those of the other contaminants stretching from Basin F northeastward to the system.

Denver Sands Update

142. Thompson et al. (1985) identified Denver formation sand zones that contained contaminants that have been associated with the alluvial aquifer at the boundary. As a result of this finding Thompson et al. (1985) recommended that a hydrogeologic and contaminant study of the Denver formation sands be conducted. Additionally, it was recommended that the monitoring of the boundary system be expanded and improved to gather data concerning the hydrology and contamination conditions. The FY 85-86 monitoring programs were expanded and modified to include monitoring of the Denver formation.

143. At the time of the 1984 North Boundary System performance evaluation, the contamination identified in the Denver sands was being intercepted by the

Denver dewatering wells and treated by the system. As indicated by Thompson et al. (1985), the operation of these wells was viewed as potentially causing the contamination problem. Therefore, the operation of the Denver dewatering wells ceased until further studies could be conducted and or monitoring data collected.

144. Table 7 contains a summary of water quality data collected from the monitoring programs for 1984-86 on the Denver sand zones. The data are from both monitoring wells and dewatering wells as shown on Plate 9 Volume II. The water quality data indicate that changes in the contaminant levels have occurred since 1984. Evaluation of the data indicates that contaminants continued to be found in some of the wells. It can not be determined from the existing data as to what role the dewatering operation may have had in the contamination problem that was identified. It is probable that the Denver ground water flows have readjusted since the pumping has stopped. The current hydrologic monitoring data indicate that the flows in the Denver sand zones is generally northward. Because of the low rate of movement of ground water in the Denver formation the monitoring data collected is insufficient to determine whether the Denver sand zones remain contaminated (possibly due to the operation of the dewatering wells or are an indication of contamination due to prior conditions).

145. A study of the hydrologic and geologic problems with the North Boundary that were identified by Thompson et al. (1985) was initiated in the 4th quarter of FY 86. This investigation, Task 36 "North Boundary System Component Response Action Assessment," will assess the condition of the bentonite system, assess the existing dewatering and recharge system and investigate and define the hydrology, geology and contamination conditions of the Denver formation in the area of the system. The purpose of this study is to assess the adequacy of these North Boundary System components to control contamination identified at the boundary and make response action recommendations for system improvements as necessary.

Contaminant Concentration Trend Analysis

146. Thompson et al. (1985) selected six alluvial monitoring wells for assessment of the long-term trends in their associated DIMP concentrations.

Table 7

North Boundary Denver Sands Formation Data Summary

Well No	Date	Chloride ppm	Fluoride ppm	DIMP ppb	DBCP ppb	DCPD ppb	Sulfur Compounds ppb
			Monitoring Wells				
23200	Dec 84	101	1.1	LT10	LT.2	LT 1	LT20
	Apr 85	103	1.0	LT10	LT.2	LT 1	LT20
	Jul 85	110	1.1	LT10	LT.2	LT 1	LT20
	Jul 86	90	-	LT10	LT.2	-	LT20
	Sep 86	92	1.07	-	LT.13	LT9.3	LT3.2
23202	Dec 84	484	1.9	270	LT.2	LT 1	LT20
	Apr 85	519	1.7	200	LT.2	LT 1	LT20
	Jul 85	567	1.4	200	LT.2	LT 1	LT20
	Jul 86	554	-	195	LT.2	-	LT20
	Sep 86	501	LT 1	207	LT.13	15	LT3.2
23203	Dec 84	406	5.0	417	0.33	1069	21.1
	Apr 85	294	1.7	400	0.20	366	LT20
	Jul 85	123	0.7	105	LT.2	49	LT20
	Nov 85	78.4	0.7	36.8	LT.2	200	LT20
	Jul 86	20.6	-	195	LT.2	-	LT20
	Sep 86	517	2.06	553	0.35	360	52.4
23204	Dec 84	254	1.4	292	3.62	-	93.5
	Apr 85	182	1.1	100	1.0	34.9	LT20
	Jul 85	255	1.0	77	0.7	31.0	LT20
	Nov 85	252	1.0	80.3	0.5	20.0	LT20
	Jul 86	232	-	67.6	0.24	-	LT20
	Sep 86	240	LT 1	236	1.6	20.0	51.2
			Dewatering Wells				
23336	Jun 84	103	1.46	LT10	LT.2	LT 1	LT20
	Mar 85	410	6.0	675	2.37	30.0	72.4
	Sep 85	123	1.2	LT10	LT.2	LT 1	LT20
	Jul 86	104	1.21	LT10	LT.2	-	LT20
	Oct 86	105	1.43	LT10	LT.2	LT 1	LT20
23337	Aug 83	900	1.87	2610	LT.2	LT 1	LT20
	Mar 85	417	2.0	4120	LT.2	LT 1	LT20
	May 85	317	2.4	4870	LT.2	LT 1	LT20
	Sep 85	454	2.2	4490	LT.2	LT 1	LT20
	Jul 86	316	3.2	-	LT.2	LT 1	LT20
	Oct 86	322	2.87	4300	LT.2	LT 1	LT20

(Continued)

Table 7 (Concluded)

Well No	Date	Chloride ppm	Fluoride ppm	DIMP ppb	DBCP ppb	DCPD ppb	Sulfur Compounds ppb
23338	Jun 84	112	2.2	778	LT.2	LT 1	LT20
	Jul 86	464	2.39	1310	LT.2	LT 1	LT20
	Oct 86	494	3.04	1380	LT.2	2.0	LT20
23339	Aug 83	400	2.03	73.6	LT.2	LT 1	LT20
	May 85	441	1.9	208	LT.2	LT 1	LT20
	Sep 85	558	2.0	20.1	LT.2	LT 1	LT20
	Jul 86	442	2.2	10.5	LT.2	LT 1	LT20
	Oct 86	470	2.49	LT10	LT.2	LT 1	LT20
23340			Not Sampled				
23341	Jun 84	350	5.0	486	1.83	606	80.1
	Mar 85	329	5.0	456	1.18	624	51.3
	May 85	535	3.0	639	LT.2	270	93.2
	Sep 85	535	2.9	579	LT.2	600	43.2
	Jul 86	609	4.0	610	LT.2	200	43.9
	Oct 86	611	2.67	600	LT.2	500	42.6
23342	Jun 84	220	5.0	422	6.0	132	172.8
	Mar 85	206	4.0	348	10.1	LT 1	128.4
	May 85	218	7.0	297	1.44	320	161.6
	Sep 85	190	2.0	361	LT.2	300	109.7
	Jul 86	181	4.9	253	LT.2	30	49.3
	Oct 86	171	3.84	277	LT.2	200	39.6
23343	Aug 83	200	0.84	17.8	LT.2	20	LT20
	Mar 85	219	0.7	61.8	LT.2	20	LT20
	May 85	240	0.9	63.5	LT.2	LT 1	LT20
	Sep 85	68.3	1.3	66.0	LT.2	LT 1	LT20
	Jul 86	280	1.03	67.9	2.88	LT 1	LT20
	Oct 86	278	0.87	71.8	2.01	LT 1	LT20

The locations of the six alluvial wells are shown in Plate 1, Volume II of this report and are identified using darkened circles. Three on-post and three off-post wells were selected based on their location in the area of highest DIMP concentration and the completeness of their respective data bases. The goal of this assessment was to determine the long-term impact of the North Boundary system on the concentration of contaminants both on and off-post north of the system.

147. This assessment has been continued through FY85 and FY86 and expanded to include an analysis of the trends in DBCP concentrations. Table 8 presents a summary of the characteristics of each well including well depth, screened interval, and a description of the aquifer material found at the screened interval. Trend plots for DIMP and DBCP for each well have been prepared and are presented as Figures 36 through 47. Both a least squares trend line and a three year moving average trend line have been added to the plots for illustrative purposes.

Table 8

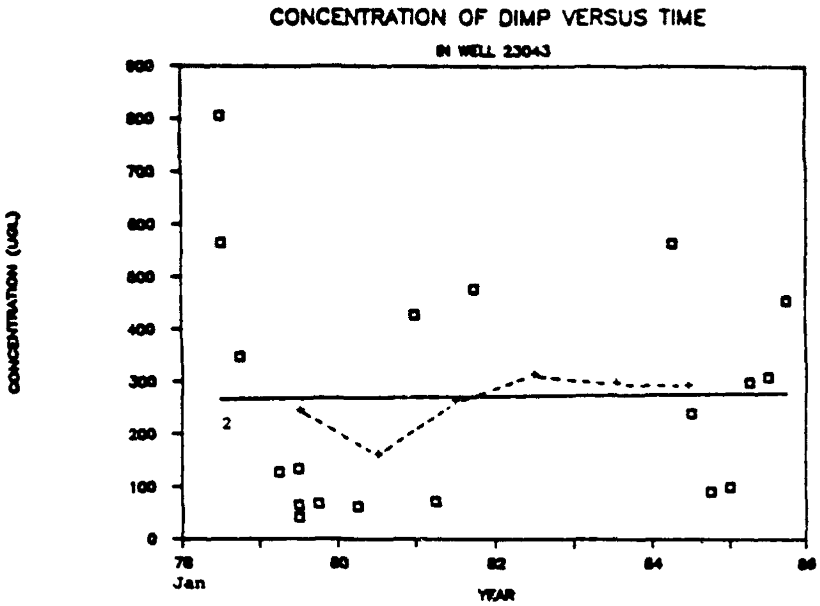
Characteristics of Trend Wells*

Well Number	Depth (ft)	Screened Interval (ft)	Aquifer Material
37308	21.5	16.5 - 21.5	sandstone
37309	24.0	19.0 - 24.0	coarse sands
37313	30.0	25.0 - 30.0	sandstone
23043	22.6	16.7 - 20.7	coarse sand
23047	27.3	21.9 - 25.9	medium sand
24006	24.8	12.8 - 18.8	sand/clay

* All wells are alluvial wells

On Post Monitoring Wells 23043, 23047 and 24006.

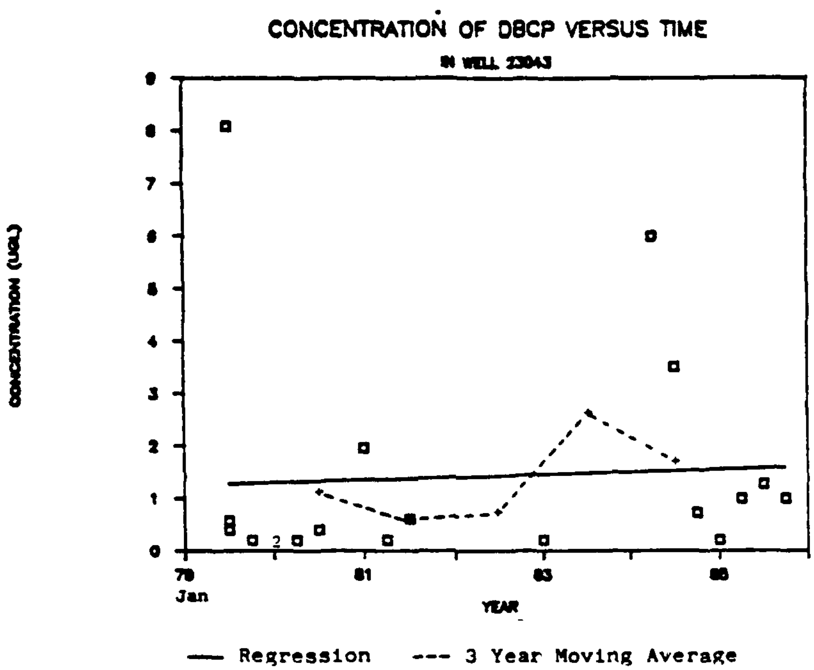
148. Well 23043 located at the corner of D Street at 96th Avenue, is possibly screened in a Denver water-bearing sand. During FY84, the DIMP concentration associated with the well decreased from a high of 564 ppb to a low of 91 ppb. During FY85, the DIMP concentration increased from 100 ppb to 456 ppb by the end of the year. The DIMP concentrations have varied



— Regression --- 3 Year Moving Average

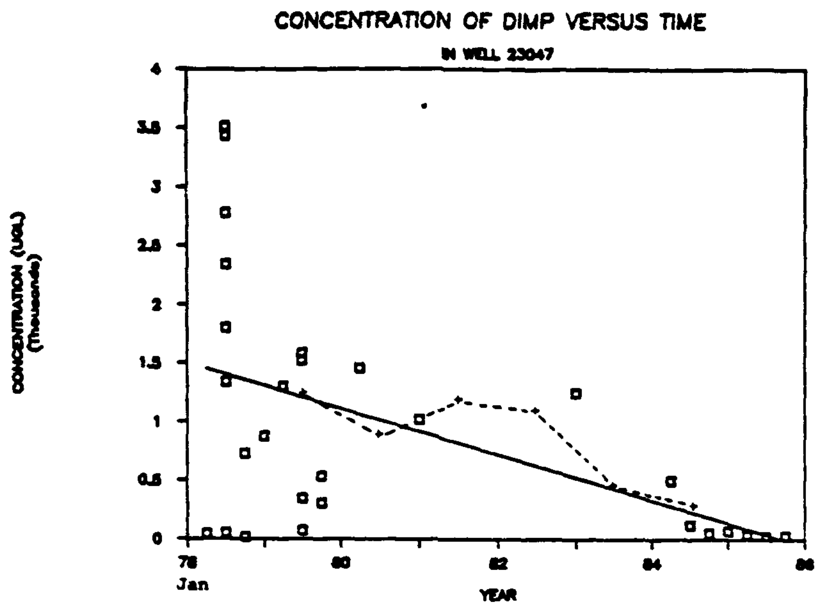
Sample Date	DIMP Concentration	Sample Date	DIMP Concentration
Mo/Yr	ugl	Mo/Yr	ugl
Jul/79	807	Oct/81	478
Aug/78	565	Apr/84	564
Aug/78	223	Jul/84	240
Sep/78	223	Oct/84	91
Dec/78	348	Jan/85	100
May/79	128	Apr/85	300
Jul/79	42	Jul/85	310
Jul/79	65	Nov/85	456
Sep/79	135		
Dec/79	68		
Jun/80	52		
Jan/81	429		
Apr/81	72		

Figure 36. DIMP trend well 23043



Sample Date	DBCP Concentration	Sample Date	DBCP Concentration
Mo/Yr	ugl	Mo/Yr	ugl
Jul/79	.57	Apr/84	5.99
Jul/79	LT .40	Jul/84	3.51
Sep/79	8.09	Oct/84	.73
Dec/79	LT .20	Jan/85	LT .20
Mar/80	LT .20	Apr/85	1.00
Mar/80	LT .20	Jul/85	1.28
Jun/80	LT .20	Nov/85	1.00
Sep/80	.40		
Jan/81	1.96		
Apr/81	LT .20		
Oct/81	.61		
Feb/83	LT .20		

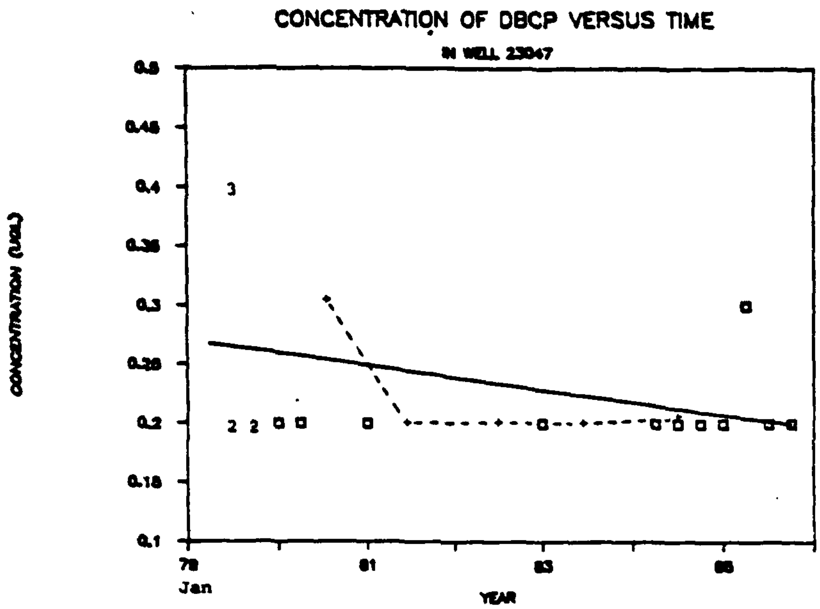
Figure 37. DBCP trend, well 23043



—— Regression ---- 3 Year Moving Average

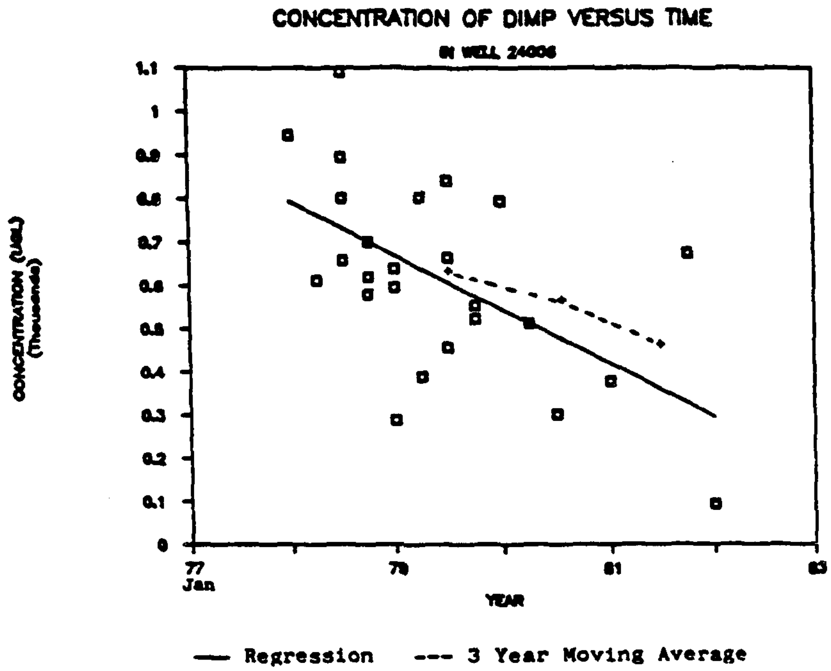
Sample Date	DIMP Concentration	Sample Date	DIMP Concentration
Mo/Yr	ugl	Mo/Yr	ugl
Jun/78	47	Nov/79	308
Jul/78	54	Dec/79	537
Jul/78	3514	Jun/80	1460
Aug/78	3436	Jan/81	1020
Aug/78	2341	Mar/83	1250
Aug/78	2780	Apr/84	501
Sep/78	1800	Jul/84	123
Sep/78	1340	Oct/84	53
Oct/78	19	Jan/85	70
Nov/78	730	Apr/85	40
Mar/79	876	Jul/85	26
May/79	1303	Nov/85	31
Jul/79	1588		
Jul/79	1526		
Aug/79	73		
Sep/79	348		

Figure 38. DIMP trend well 23047



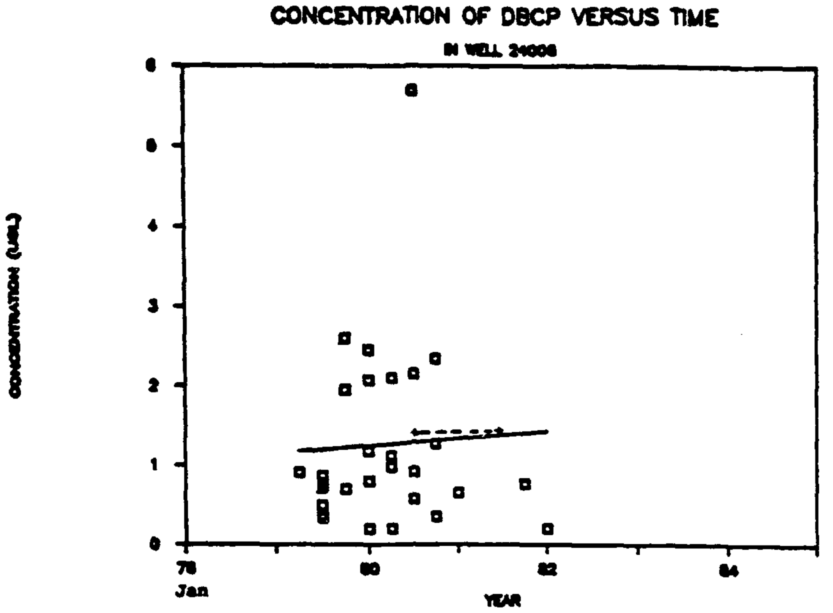
Sample Date	DBCP Concentration	Sample Date	DBCP Concentration
Mo/Yr	ugl	Mo/Yr	ugl
Jul/79	LT .40	Apr/84	LT .20
Jul/79	LT .40	Jul/84	LT .20
Jul/79	LT .40	Oct/84	LT .20
Sep/79	LT .20	Jan/85	LT .20
Sep/79	LT .20	Apr/85	.30
Nov/79	LT .20	Jul/85	LT .30
Dec/79	LT .20	Nov/85	LT .20
Mar/80	LT .20		
Jun/80	LT .20		
Jan/81	LT .20		
Jan/83	LT .20		

Figure 39. DBCP trend, well 23047



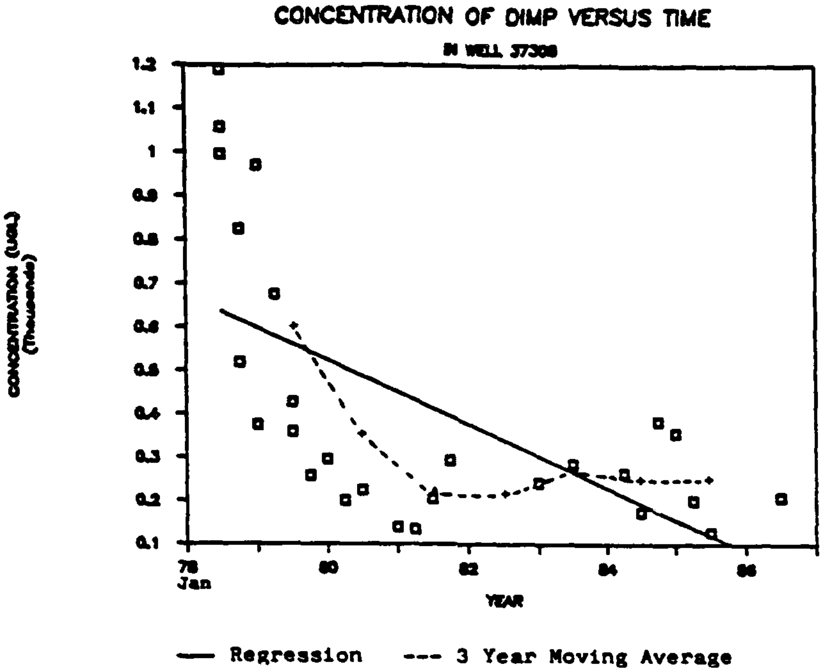
Sample Date	DIMP Concentration	Sample Date	DIMP Concentration
Mo/Yr	ugl	Mo/Yr	ugl
Jan/78	946	Aug/79	457
Apr/78	611	Oct/79	524
Jul/78	895	Nov/79	555
Jul/78	800	Jan/80	795
Aug/78	1090	Apr/80	513
Sep/78	657	Jul/80	302
Oct/78	700	Mar/81	379
Oct/78	579	Oct/81	675
Nov/78	620	Feb/82	93
Jan/79	596		
Jan/79	639		
Mar/79	288		
Apr/79	390		
May/79	804		
Jul/79	842		
Aug/79	665		

Figure 40. DIMP trend, well 24006



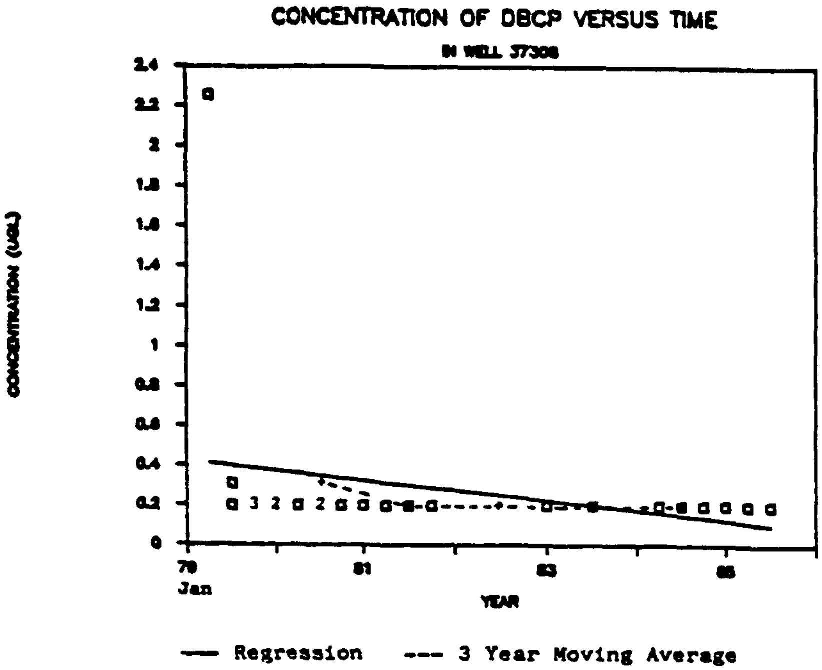
Sample Date	DBCP Concentration	Sample Date	DBCP Concentration
Mo/Yr	ugl	Mo/Yr	ugl
Jun/79	.91	Apr/80	.98
Jul/79	.87	May/80	2.10
Jul/79	.78	May/80	1.12
Aug/79	.37	Jul/80	.58
Aug/79	.34	Jul/80	.92
Sep/79	.50	Aug/80	2.15
Oct/79	.72	Sep/80	5.69
Oct/79	.70	Oct/80	1.27
Nov/79	1.95	Oct/80	2.34
Dec/79	2.60	Oct/80	1.27
Jan/80	2.45	Oct/80	2.34
Jan/80	2.07	Nov/80	.35
Jan/80	.80	Mar/81	.65
Feb/80	1.18	Oct/81	.77
Mar/80	LT .20	Feb/82	LT .20
Apr/80	LT .20		

Figure 41. DBCP trend, well 24006



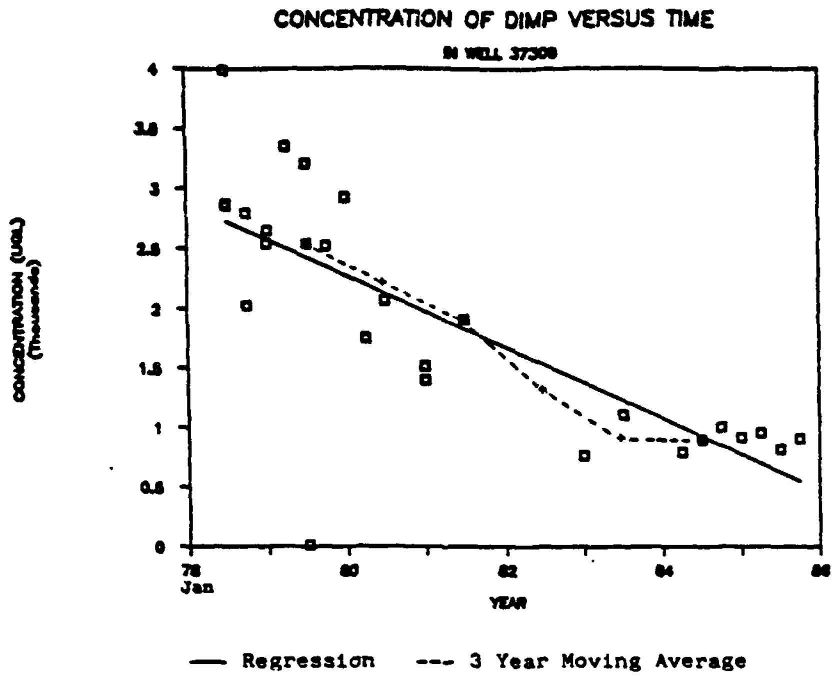
Sample Date	DIMP Concentration	Sample Date	DIMP Concentration
Mo/Yr	ugl	Mo/Yr	ugl
Jul/78	996	Jul/81	205
Aug/78	1190	Oct/81	294
Sep/78	1057	Feb/83	243
Nov/78	825	Jul/83	286
Dec/78	519	Apr/84	265
Jan/79	374	Jul/84	175
Mar/79	971	Oct/84	385
Apr/79	676	Jan/85	358
Aug/79	427	Apr/85	202
Sep/79	359	Jul/85	128
Dec/79	258	Aug/86	210
Jan/80	296		
Apr/80	201		
Jul/80	225		
Jan/81	139		
Apr/81	134		

Figure 42. DIMP trend, well 37308



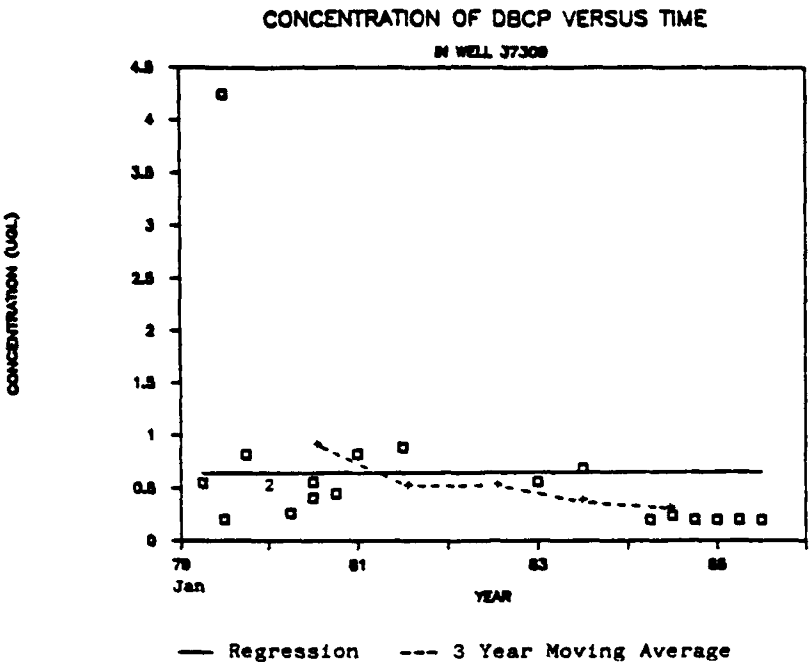
Sample Date	DBCP Concentration	Sample Date	DBCP Concentration
Mo/Yr	ugl	Mo/Yr	ugl
Jul/79	2.26	Feb/83	LT .20
Aug/79	.31	Jul/83	LT .20
Sep/79	LT .20	Apr/84	LT .20
Oct/79	LT .20	Jul/84	LT .20
Dec/79	LT .20	Oct/84	LT .20
Dec/79	LT .20	Jan/85	.20
Jan/80	LT .20	Apr/85	LT .20
Mar/80	LT .20	Jul/85	LT .20
Apr/80	LT .20		
Jul/80	LT .20		
Sep/80	LT .20		
Oct/80	LT .20		
Jan/81	LT .20		
Apr/81	LT .20		
Jul/81	LT .20		
Oct/81	LT .20		

Figure 43. DBCP trend well 37308



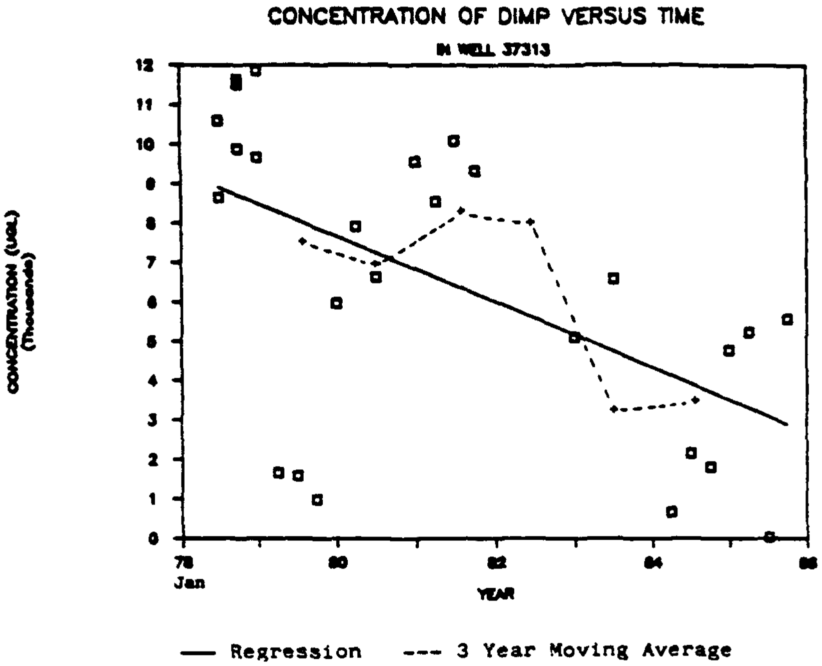
Sample Date	DIMP Concentration	Sample Date	DIMP Concentration
Mo/Yr	ugl	Mo/Yr	ugl
Jul/78	2858	Mar/81	1520
Aug/78	3990	Jul/81	1910
Sep/78	2870	Feb/83	766
Nov/78	2794	Jul/83	1110
Dec/78	2020	Apr/84	796
Jan/79	2540	Jul/84	902
Mar/79	2650	Oct/84	1010
Apr/79	3355	Jan/85	922
Jul/79	3209	Apr/85	960
Aug/79	LT 10	Jul/85	822
Sep/79	2540	Dec/85	912
Oct/79	2524		
Jan/80	2930		
Apr/80	1750		
Jul/80	2070		
Jan/81	1400		

Figure 44. DIMP trend, well 37309



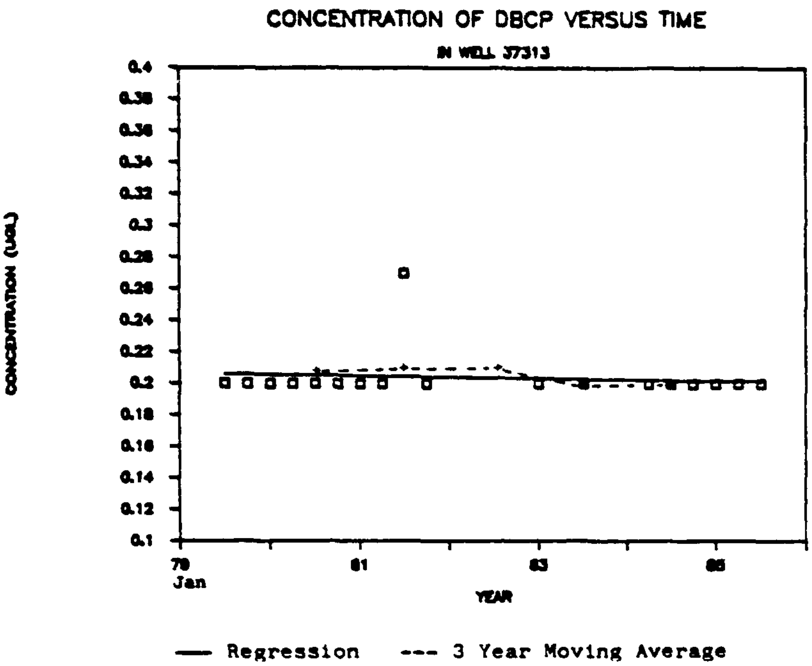
Sample Date	DBCP Concentration	Sample Date	DBCP Concentration
Mo/Yr	ugl	Mo/Yr	ugl
Jul/79	.55	Jul/81	.89
Aug/79	4.25	Feb/83	.56
Sep/79	LT .20	Jul/83	.69
Oct/79	.82	Apr/84	LT .20
Jan/80	.52	Jul/84	.24
Jan/80	.52	Oct/84	LT .20
Apr/80	.26	Jan/85	LT .20
Aug/80	.56	Apr/85	LT .20
Sep/80	.41	Jul/85	LT .20
Oct/80	.45		
Jan/81	.83		

Figure 45. DBCP trend, well 37309



Sample Date	DIMP Concentration	Sample Date	DIMP Concentration
Mo/Yr	ugl	Mo/Yr	ugl
Jul/78	10600	Oct/81	9330
Aug/78	8640	Feb/83	5120
Oct/78	11520	Jul/83	6590
Nov/78	9880	Apr/84	669
Dec/78	11640	Jul/84	2170
Jan/79	11860	Oct/84	1820
Feb/79	9670	Jan/85	4800
Apr/79	1666	Apr/85	5260
Aug/79	1590	Jul/85	24
Oct/79	990	Dec/85	5590
Jan/80	5970		
Apr/80	7920		
Jul/80	6640		
Jan/81	9560		
Apr/81	8550		
Jul/81	10100		

Figure 46. DIMP trend, well 37313



Sample Date	DBCP Concentration	Sample Date	DBCP Concentration
Mo/Yr	ugl	Mo/Yr	ugl
Aug/79	LT .20	Jul/83	LT .20
Oct/79	LT .20	Apr/84	LT .20
Jan/80	LT .20	Jul/84	LT .20
Apr/80	LT .20	Oct/84	LT .20
Jul/80	LT .20	Jan/85	LT .20
Oct/80	LT .20	Apr/85	LT .20
Jan/81	LT .20	Jul/85	LT .20
Apr/81	LT .20		
Jul/81	.27		
Oct/81	LT .20		
Feb/83	LT .20		

Figure 47. DBCP trend well 37313

considerably since 1978 but the concentration trend appears to be increasing at this time. DBCP concentrations remained generally under 1 ppb until FY84 when a high of 5.99 ppb was found. The DBCP concentrations decreased through the remainder of FY84 and then increased to around 1 ppb during FY85-86. The long-term trend indicates a slight increase in DBCP concentrations.

149. Well 23047 is located 1,000 feet west of D Street and is screened in a medium sand of low permeability. During 1978, concentrations of over 3,000 ppb of DIMP were found associated with this well. Since that time, the concentrations have generally decreased. During FY85 and early FY86, the DIMP concentrations were less than 100 ppb. DBCP concentrations for this well have generally been at or below the detection level of 0.2 ppb.

150. Well 24006, located just east of D street, has been dry since FY83. Therefore, no new assessment of trends in this well is possible.

Off-Post Wells 37308, 37309, and 37313

151. Well 37308 is located 700 feet north of the RMA boundary along Peoria Street and is possibly screened in a Denver sand. The DIMP concentration associated with this well was as high as 1,200 ppb in 1978. The concentrations decreased until the end of 1979 and then leveled off in the 100 to 300 ppb range. The concentrations found, though variable, have remained in this range throughout FY85 and into FY86. DBCP concentrations for this well have generally been at or below the detection level of 0.2 ppb.

152. Well 37309 is located 1,600 feet north of the RMA boundary along Peoria Street and is screened in a coarse sand. DIMP concentrations as high as 4,000 ppb were found associated with this well in 1978. Since that time, the concentrations have decreased steadily. During FY85, the DIMP concentrations were below 1,000 ppb and appear to be leveling off. DBCP concentrations above the detection level were found associated with this well through FY84. During FY85 the concentrations decreased to below 0.2 ppb and remained there.

153. Well 37313 is located one-half mile northwest of the treatment system along Highway 2 in the First Creek drainage system. DIMP concentrations in excess of 11,000 ppb were found associated with this well in 1978 and 1979. The concentrations have varied greatly since that time but there appears to be a downward trend in concentrations through FY84. The DIMP concentrations then increased in FY85 to over 5,000 ppb. DBCP concentration for this well have generally been at or below the detection level of 0.2 ppb.

154. In summary, the DIMP and DBCP concentrations associated with well 23043 have been highly variable with no obvious long-term trends. The concentrations of both contaminants increased during FY85 and early FY86. In wells 23047, 32308 and 37313, the DIMP concentrations reflect a long-term downward trend with well 32313 showing an increase during FY85. The DBCP concentrations of wells 23047, 32308 and 37313 have generally been at or below the detection level. Finally, DIMP and DBCP concentrations associated with well 38309 reflect a long-term downward trend.

PART V: ASSESSMENT OF SYSTEM EFFECTIVENESS

Introduction

155. The North Boundary System was constructed for the primary purpose of reducing the contaminant levels in the ground water migrating off RMA to acceptable levels based on approved standards and criteria where available (Rocky Mountain Arsenal Contamination Control Program Team 1983). It should be noted that "acceptable levels," as that term is used in this assessment, may or may not be equivalent to action levels currently being developed as part of the offpost endangerment assessment. Once action levels for offpost groundwater are established, they will be addressed as part of the ongoing evaluation of the need for improvements to the North Boundary System (PM, RMA, Task 36).

156. In order to evaluate the overall effectiveness of the system in achieving the above stated purpose, the ability of the system to intercept and control contaminated ground water flow and to treat the contaminants in this flow to an acceptable level must be assessed. It is emphasized at this point that the system was designed to intercept and treat the ground water flowing in the alluvium off the north boundary of the Arsenal, to monitor, and if necessary, to remove and treat ground/water from the upper Denver sands known to be contaminated at the time. The treatment plant was specifically designed to remove organic contaminants (DIMP, DCPD, aldrin, dieldrin, endrin, DBCP, and the combined organo-sulfurs) to below their maximum operating levels (MOL), so that ground water down gradient of the system would not contain concentration of contaminants exceeding acceptable levels.

157. Analysis of the Denver formation during the original design work for the system (Black and Veatch, 1980) indicated a potential for ground water flow in lenticular Denver sand beds beneath the barrier alignment. Several alternative designs were developed to address control of contaminants in the upper Denver sands (Black and Veatch, 1980). Based on the existing water quality, need for control in the areas of concern and overall costs, it was decided to locate the barrier at sufficient depth to cutoff ground water flowing in the upper Denver sands at several locations along the barrier. A comprehensive assessment of the need to deepen the barrier along the pilot system alignment resulted in a decision to install monitoring/dewatering

wells, due to the extremely low flows and low levels of contaminants in the ground water in the Denver sands (Black and Veatch 1980). The hydrologic monitoring data obtained during this study still indicate that the direction of flow in the Denver sand units is generally northward, and that the hydraulic driving force produced by the water levels in the alluvium upgradient of the barrier has been reduced during FY85 and FY86. This reduction has resulted from a gradual decrease in ground water levels due to increased system dewatering rates.

Assessment of Operational Effectiveness

158. The ground water elevation maps (Plates 1-8 Volume II) prepared for this report indicate that the system has continued to control alluvial flow along the North Boundary System of RMA. The word alluvial is emphasized since the system barrier was primarily designed to intercept flow in the Alluvial formation.

159. System operating reliability is an important factor in the overall effectiveness of the system, since system failures can cause large fluctuations in water levels and resulting hydraulic driving forces. The alterations and repairs conducted during FY85 and FY86 resulted in a significant improvement in the operating reliability of the system. The modifications made should reduce the amount of system downtime previously experienced due to mechanical failures. The reduction in system downtime, along with a reduction in the migration of carbon fines from the adsorbers and the periodic cleaning of the dewatering and recharge wells, has greatly reduced the potential for temporary high ground water levels upgradient of the barrier. These activities will reduce the potential hydraulic force on ground water to flow through and under the barrier.

160. The contaminant concentration maps indicate that the control system is intercepting essentially all of the contaminants distributed in the alluvial aquifer having the potential to migrate toward the north boundary of RMA. Although an extensive assessment of the distribution of contaminant concentrations north of the barrier is not possible due to the limited data in this area, the existing historical data indicate a general downward trend in contaminant concentrations over the past 7 to 8 years that the N.B. Containment/Treatment System has operated.

161. The data obtained from the analysis of influent and effluent samples from the treatment plant indicate that the plant is effectively removing organic contaminants. No concentrations of organic contaminants above their respective maximum operating levels were found in the effluent from the plant. The concentrations found were generally below their respective analytical detection levels. Inorganic contaminants such as chloride and fluoride are not being removed by the treatment system. However, treatment plant influent/effluent are monitored for fluoride and chloride and by proper control of influent streams, the effluent fluoride concentration is maintained below the maximum operating level of 4.0 ppm at all times and the effluent chloride concentration is on an average basis below the maximum operating level of 250.0 ppm.

162. Thus, based on the available data, the North Boundary System is reducing the off-post migration of contaminated ground water as designed. The treated water being recharged contains levels of organic contaminants generally below detectable levels. The concentrations of organic contaminants still found in the ground water north of RMA, are believed to be residuals from historical migrating plumes. Ground water in this area moves relatively slowly, and, thus, considerable time is required for the contaminant concentrations to dissipate. The concentrations in this area should continue to trend downward.

PART VI: CONCLUSIONS AND COMMENTS

Conclusions

163. Based on the evaluation of the data, the following conclusions have been drawn:

a. The North Boundary System is effectively reducing the off post migration of contaminated ground water in the alluvial aquifer in accordance with the original system design objectives. Historical data to include the current study period (FY85-86) indicate a general downward trend in contaminant concentrations over the past 7 to 8 years in the area north of the barrier.

b. During FY85-86 timeframe, ground water flow continues to follow the same patterns described by Thompson et al. (1985). The flow is primarily within the buried stream valley through Sections 23 and 24. Most of the contaminant plumes are associated with this groundwater flow.

c. The control system is intercepting essentially all of the contaminants distributed in the alluvial aquifer migrating toward the North Boundary of RMA.

d. For FY85 and FY86, the average water table level upgradient of the barrier appears to be decreasing slowly with time, with the fourth quarter FY86 level the lowest in three years. This trend implies that the dewatering rates for FY85 and FY86 are approximating ground water flow rates toward the system.

e. The North Boundary System recharge continues to be less than optimal in achieving the desired distribution of ground water north of the barrier. This condition is reflected in the variability of the ground water levels immediately north of the system.

f. The treatment system is effectively removing organic contaminants from the influent to the system. The ground water being recharged contains levels of organic contaminants generally below detectable levels. Inorganic contaminants such as chloride and fluoride are not treated. However, treatment plant influent/effluent are monitored for fluoride and chloride and by proper control of influent streams, the effluent fluoride concentration is maintained below the maximum operating level of 4.0 ppm at all times and the effluent chloride concentration is on an average basis below the maximum operating level of 250.0 ppm.

g. The alterations and repairs conducted during FY85 and FY86 resulted in a marked improvement in the operational reliability of the North Boundary System.

Comments

164. The FY84 system evaluation report indicated the need to assess system components. This current evaluation report indicates the need to improve the distribution of ground water immediately north of the system. In response to the conclusions/recommendations generated in the above mentioned reports, the Program Manager for RMA Contamination Cleanup initiated study efforts during 1986 to support North Boundary interim response actions. The following specific interim response actions are in progress:

1. The design of an improved recharge system (deep trench) for the west and central portions of the system; installation of this system is expected during the early fall of 1987.
2. A comprehensive assessment of the North Boundary System components (Task 36) to include these elements: the physical condition of the barrier, the geotechnical/hydrologic conditions of the Denver Sands immediately adjacent to the barrier, and the adequacies of the dewatering/recharge system; results of this assessment will provide data for an interim response action to upgrade the North Boundary System.

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